Integration of Unmanned Aerial Vehicles and Aerial Photogrammetry into a Civil Engineering Course to Enhance Technology Competency

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Abstract

Given the increasing use of technology in civil engineering, it is important for students to be proficient in learning and using new technologies. In academic settings, this priority translates into students gaining experience using technology and learning about potential applications. Since technology evolves, it is more important to cultivate technology competency in students than to teach specific technologies, software, coding languages, etc.

In this project, our objective was to integrate technology into the civil engineering curriculum by introducing an activity into an existing course where students learned about unmanned aerial vehicles (UAVs) and aerial photogrammetry. Our use of UAVs was motivated by the increasingly common industry practice of using aerial systems for monitoring buildings and environments. We integrated this activity into an existing civil engineering elective course titled 'Heavy Construction Methods.' In the classroom, students learned about the principles of UAVs and aerial photogrammetry. Students then practiced these principles by observing a UAV flight (conducted by a FAA licensed drone pilot), setting and recording coordinates for ground control points, collecting field data, and using Autodesk software (Recap, Recap Photo, and Civil 3d) to create digital surface models. This activity spanned two class sessions. Student attitudes towards technology and learning were captured using a questionnaire conducted in class.

A major finding of this project was that faculty can work with students to better integrate technology learning into classroom settings, making technology more approachable and creating meaningful experiences for students. One of the challenges we found in introducing technology into the classroom is that the instructor may need to update their skill set and become proficient in using the technology first. Institutional support was also important to provide and maintain the appropriate equipment and software. Students appreciated the "real world" application, outdoor setting of the first session, and collaborative nature of the activity.

Overall, the project demonstrates how technology can be integrated into the civil engineering curriculum in a relevant manner and how collaborative and hands-on activities can cultivate students' ability in using technology.

Introduction

Civil engineering is progressively becoming more technology-dependent, requiring that civil engineers be adept at using and adapting to new technologies. Given the increasing reliance on technology, cultivating technology competency in civil engineering students is warranted. Graduates need to be familiar with and competent in using sensors and instruments, especially for automated data collection and subsequent analysis of the data sets generated. Graduates should be comfortable learning new technologies and hardware, adopting technology from other disciplines (e.g. electrical engineering) to meet the needs of the civil engineering discipline.

As an example of technology in industry, Unmanned Aerial Vehicles (UAVs) are being increasingly used by civil engineers in a variety of applications [1]. UAVs are used for structural health monitoring, levee assessment, earthwork quantity estimating in construction, and water resource management [2-5]. The potential advantages of deploying UAVs in these applications include expanded data sets, more accurate field measurements, the ability to access areas that are dangerous or remote, and faster and less intrusive study methods (e.g. compared with field crews and watercraft).

The objective of this study was to integrate UAV aerial photogrammetry into the civil engineering curriculum in order to introduce students to new technologies. An in-class activity, spanning two class periods, was integrated into an existing construction engineering course. On the first day of the activity, students observed a UAV flight conducted by an experienced and licensed drone pilot. The students set ground control points and recorded the coordinates using surveying equipment. The students also recorded other field data as part of the exercise. The aerial images collected during the UAV flight were then used during the second day of the activity to create a digital surface model of an area on campus that contains a bridge spanning a river with flood-protection levees on either side. In addition to having students gain experience using new technologies, integrating UAVs into the coursework was intended to improve students' engagement with relevant and current issues and tools in civil engineering. The research questions posed in this study are:

- Can UAV technology be integrated into the civil engineering curriculum with readily available tools, at a reasonable cost, and without significant investment in resources?
- Do experiences with UAV technology and mapping improve student engagement and attitudes about trying new technologies?

Literature Review

At the time that this paper was written, we found little evidence of UAVs being used in civil engineering curricula. Pereira et al. [6] integrated UAVs and photogrammetry into a building information modeling (BIM) course, part of a construction engineering program, where students piloted UAVs and used photos to create three dimensional models of objects located indoors. Autodesk software was used in that project: Recap was used to generate the point cloud that was then imported into Revit [6]. Sharma and Hulsey [7] used a UAV for aerial photogrammetry as an exploratory task to investigate its potential in the university setting although it did not appear that they were integrating UAVs into teaching. Other faculty reported plans to use UAVs for mapping in a Construction Surveying course as part of a Civil and Construction Engineering Technology program [8]. Opfer and Shields [9] provided an overview of how UAVs could be incorporated into the construction engineering curriculum.

Although we found little evidence of UAVs being used in civil engineering courses, we did find that UAVs are being used in other engineering disciplines. As an example, UAVs were used by Kosmatin Fras and Grigillo [10] to study active learning methods in a master's program of Geodesy and Geoinformation, a program where students study photogrammetry and remote sensing methods. Wlodyka and Dulat [11] used UAVs in a first year design course where students design sensors for off-the-shelf UAVs—the main purpose of this activity was introducing students to project-based learning, project management, and teamwork skills. McGoldrick et al. [12] used UAVs in courses with undergraduate and graduate students to study wind turbine blades. Although there is much evidence in the literature on the use of UAVs in the electrical and computer engineering space—where UAV technologies are being developed and used by students specializing in such technology—we were more interested in applications of UAVs outside the disciplines in which they are being developed.

Integration of UAV Technology into a Civil Engineering Course

The UAV educational activity was introduced into an existing civil engineering elective course titled 'Heavy Construction Methods.' The course has no prerequisites except that students must have junior or senior standing. Both civil engineering and engineering management majors can take this course. The course covers topics such as earthwork, production estimating, concrete batching and construction, asphalt and paving, steel construction, pumps and air compressors, scheduling, cost estimating, and contracts. The course typically includes several field trips. Given the emphasis on earthwork and production estimating in the course, having the students learn about aerial photogrammetry using UAVs seemed like a relevant application. For example, students calculate cut and fill earthwork volumes, a task that would benefit from use of UAVs and subsequent model development for computer-generated estimates.

The UAV educational activity was integrated into the Fall 2019 class that had 15 students, consisting of a mix of juniors and seniors. Nine of the students were male and six were female. One unique feature of this class was that we were able to take a field trip to the local heavy construction equipment dealership and meet with a supplier of construction instrumentation that includes terrestrial LiDAR instruments and GPS devices that attach directly to heavy construction equipment for improved precision. The educational activity had the following learning objectives that were provided to the students in the assignment handout:

- Define terminology used in aerial photogrammetry with UAVs.
- Summarize aerial photogrammetry mapping concepts.
- Collect ground control point data and incorporate it into map processing.
- Generate a three-dimensional map with aerial images collected by a UAV.

There were several motivations for integrating UAV technology into this construction engineering course. One was that there is an increasing use of technology in the construction industry and UAVs represent one of the technologies being frequently used. In developing this activity, we were in contact with a local engineering/surveying firm to make sure that our approach was consistent with industry practices (e.g. flying height, setting of ground control points). An additional influence was our Industrial Advisory Panel—some members have recommended that students gain exposure to Civil 3d, and the UAV activity provided a simple way to integrate that software. Students returning from co-ops and internships have also expressed the importance of basic familiarity with Civil 3d.

An additional motivation for integrating UAVs into civil engineering coursework is supported by the ABET criteria. In the ABET Criteria for Accrediting Engineering Programs, 2019 – 2020, Criterion 3: Student Outcomes, parts 1, 2, and 7 are relevant in that the UAV activity applies scientific principles, involves teamwork, and is an application of acquiring and applying new knowledge. Criterion 5: Curriculum, states that the curriculum must include '…utilizing modern engineering tools' and the UAV clearly meets this requirement. Finally, Criterion 7: Facilities requires programs to have 'modern tools' and provide 'guidance regarding the use of the tools' and we have met both of these expectations with this activity.

Assessment Methods

The main assessment tool was a questionnaire that was distributed and collected in class at the start of the activity (attached). The purpose of the questionnaire was to assess student attitudes about their experiences learning new technologies and to gain insight on how to better teach new technologies. The questionnaire was reviewed and approved by the campus IRB office.

Due to the exploratory nature of the activity (it was the first implementation), the in-class assignment was not graded although it will be graded in future offerings of the course. The following questions about aerial photogrammetry were included on an exam and were graded:

1. What is aerial photogrammetry? Explain.
2. What does UAV stand for? Spell it out.
3. What is the difference between "end lap" and "side lap" in aerial photogrammetry?
4. Why are ground control points (GCP) used in aerial photogrammetry?

Data on students' ability to answer the above questions were collected and are reported below.

Tools used in the UAV Educational Activity

The UAV used in the activity was a Phantom 4 Pro Plus (DJI, Shenzhen, China). The university maintains this UAV as part of library resources, and it is available for educational use on campus. The UAV is flown by one of two staff members who both maintain FAA drone pilot licenses. The surveying equipment used was a Hiper V (Topcon Positioning Systems, Tokyo, Japan), a global positioning system device (GPS). This GPS instrument is used in our civil engineering surveying course.

The software used for aerial map creation was Recap Photo, Recap, and Civil 3d (Autodesk, San Rafael, CA). We hold an educational license for Autodesk products, so using this software made more sense than adopting software specific to aerial photogrammetry. The Recap Photo software is used to create digital surface models using images (the images can be aerial or terrestrial). Model generation using Recap Photo is cloud-based. The Recap software is used to manage the model created in Recap Photo, which includes removing extraneous points from the model and correctly irregularities. Recap Photo can also be used for editing and exporting models to different file formats. Finally, Civil 3d is used to insert the model and create a surface, allowing users to calculate volumes, slopes, and other features.

The educational license for Autodesk introduced some limitations into the educational activity. In the educational version of Recap Photo, there is a limit of 100 images that can be processed at any one time and the models cannot be stitched together in the educational version of Recap. The educational version of Recap also lacks the full functionality in that it limits the use of regions that are helpful for isolating parts of the point cloud that are 'noise' and should be removed. Using regions (layers), extraneous points can be placed on a different region for temporary removal instead of completely removing these points from the model.

UAV Educational Activity: Field Work (Day 1)

On the first day of the activity, students were introduced to UAVs and aerial photogrammetry in the classroom. A handout was distributed that explained the key concepts and terminology. The concepts covered were: relevant applications, UAV components, correction of images, mosaic of images, necessary end lap and side lap in images collected by the UAV, GCPs, coordinate systems, and datums. Students watched a short video showing how UAV images are collected at a construction site and how GCPs are set. Roles and responsibilities for the field portion of the activity were assigned.

Immediately after the classroom meeting, students mobilized to the study site with the surveying equipment where they met the UAV pilot who was setting up the UAV. The study site was a section of the Calaveras River that flows through campus. The Calaveras River is located in Northern California and extends from the Sierra Nevada Mountains to its confluence with the San Joaquin River that discharges into the Sacramento-San Joaquin River Delta and leads into San Francisco Bay [13]. On campus, a limited-access bridge connects the north and south parts of campus and provides access for maintenance vehicles, bicycles, and pedestrians. Flood control levees are located on either side of the river. Our goal was to map a section of the river that included the access bridge and levees.

Students were actively involved during the UAV flight at the study site. First, some of the students set up the ground control points while others set up the surveying equipment. Then, students observed the UAV flight and image collection. The pilot gave a short presentation on the objectives in conducting the flight and on some of the requirements in using UAVs (e.g. licensure). His presentation reinforced the concepts covered in the classroom, including flying height and overlap percentages. While some students were collecting data on the ground control points, other students were collecting data on physical measurements (e.g. bridge and bike path width) to check map accuracy and taking photos of the study site. A handout was provided to students completing ground control data collection; the purpose of the handout was to provide basic instruction on the surveying equipment.

Following the field portion of the activity, the pilot transferred the images (225) from the UAV and the data from the GPS device was obtained and recorded in a spreadsheet.

UAV Educational Activity: Computer Lab (Day 2)

On the second day of the activity, students worked in the computer lab to create maps (digital surface models) of the study area using the UAV images. A handout was provided that explained, step-by-step, how to generate surface models using aerial images. The aerial images were also transferred to the students.

Students first learned how to generate the digital surface models using Recap Photo. Students selected images to include in the model. They then identified the ground control points and the corresponding coordinates with the appropriate coordinate system selected in the software (California Zone III NAD 83 in our area). After the coordinates of the ground control points were defined, students manually identified each ground control point in at least four of the images. Although this task must be done manually, the GPS data (lat-long) contained within the meta-data of the images assists in this task (the software can recognize which images may apply to each point). Next, students submitted the information for digital surface model creation. Since model generation is cloud-based and potentially time-consuming, students were provided with the finished model after finishing this step. The digital surface model files created by Recap Photo consist of a Recap project file (*.rcp) and a mesh file (*.rcm).

After receiving the digital surface model created by Recap Photo, students opened the model in Recap to view and edit. The process of editing models was reviewed in class, with students receiving instruction on what features should be edited and how to modify the model. In the study area used, editing primarily consists of removing points that represent 'noise' that is caused by vegetation (e.g. trees), shadows, glare, and people within the images used. Editing can also include 'fixing' parts of the model where there are holes or other problems. As part of this step, students were able to check some of the dimensions of features that they recorded in the field (e.g. bridge width) to verify model accuracy.

Finally, students created a drawing in Civil 3d and attached the digital surface model as a point cloud. Note that it is important to first define the coordinate system of the drawing so that the model is attached in the correct geo-location. After this step, students were able to verify ground control points, top of levee elevation, etc. Then, a Civil 3d surface was created using the Recap model point cloud. Students could then view and rotate the point cloud and surface within the software. Although we lacked time to pursue other uses of the Civil 3d drawing produced, students received instruction on modifications that could be done within the drawing such as estimating quantities, estimating vegetation, or placing structures in the study space.

Assessment of the UAV Educational Activity

The main assessment tool used in evaluating the education activity was the questionnaire, and this tool provided insight into the students' experiences and comfort levels with technology. Almost all students responded to the questionnaire (14 out of 15). The responses indicate that some students (29%) had prior experience with UAVs and half had experience making maps. Many of the students (43%) had taken the surveying course, which had relevance to this activity and this experience was apparent when the students set up the GPS equipment and recorded the ground control point data. While most students (71%) reported having experience with electronics, their reported comfort level was low (Likert score of 3.3 +/- 0.7 on a scale of 1-5). Students also reported low comfort levels using new software (Likert score of 3.5 +/- 0.5 on a scale of 1-5). These results support the idea that it is important for civil engineering students to gain experience using new technology and software, and that the introduction of such technology needs to be undertaken with care and with sufficient support and instruction.

A surprising result of the questionnaire data was that students reported low understanding of which technologies are used in industry (Likert score of 3.2 +/- 0.7 on a scale of 1-5). This result suggests that communicating relevant applications is needed. Applications were reviewed in the initial handout. Students also had the opportunity to learn about applications through other experiences in the class (e.g. field trips). In an informal discussion following the activity, students commented that they could see many applications for the technology in civil engineering. They also commented that the content fit well with a building information management (BIM) course that many were taking concurrently.

In addition to providing insight into students' experiences with technology, the questionnaire revealed information related to student learning preferences. Most students (79%) indicated that they would rather do field work than lab work and most (93%) indicated that they prefer teamwork activities over independent assignments, suggesting that a fieldwork-based activity such as use of UAVs is a good strategy for engaging civil engineering students.

In addition to collecting data from the questionnaire, data were collected by reviewing exam scores. Students did well answering the UAV questions on the exam, earning 87% of the total points available. The high scores indicate understanding of the technical content covered in the educational activity. The average score on the UAV questions was higher than the average score on the exam.

Review of the Educational Activity

Overall, the activity had many positive aspects, especially in the field work portion of the activity. The UAV flight went well, likely because we have an experienced pilot and a good UAV system. The amount of time allotted was sufficient (1.75 hour class sessions). The students actively participated in the field work, completing the tasks assigned. Setting up and using the surveying equipment provided a nice task for the students—even leveling the instrument was challenging since it had been a year or more since they had taken the surveying course. An additional positive feature of the field work was that the video shown in class fairly accurately resembled the work performed. The function and importance of the ground control points was apparent. Technology issues such as shadows (the class started at 3:00 pm), vegetation, and pedestrians were interesting since these features can impact image collection and map generation.

The computer lab portion of the activity also had many positive aspects. The study site was interesting, containing features such as the bridge, levees, bike path, vegetation, and river. The UAV survey yielded a nice digital surface model (Figure 1). Some editing of the model was needed to remove extraneous vegetation that conveyed the importance of data processing and the functionality of the point cloud. Using Autodesk software proved to be a good choice since the students were familiar with Autodesk products and the process of model generation and insertion into Civil 3d was straightforward. The students were able to view the 3D surface model as 2D topographic maps and contour plots, which is a valuable exercise for civil engineering students.

Figure 1. Map of the Calaveras River on the University of the Pacific campus created using 100 UAV images and five ground control points.

In addition to positive aspects of the activity, there were several challenges encountered. The most significant challenge was in using the GPS equipment. The first author encountered issues with the GPS equipment on the day of the activity, delaying collection of ground control point data. This issue has since been remedied by additional training on the instrumentation. Instructors planning to integrate this activity into their own courses are advised to become very familiar with the GPS equipment in advance.

An additional challenge encountered in carrying out the activity was that there were software installation issues related to how the educational license is managed. The fully functional Recap Photo software was not installed on the computers at the time of the activity. Fortunately, the first author had already created the digital surface model so students were able to use the previously developed model after practicing the procedure of model generation in Recap Photo. Giving the students the model proved to be a better approach for an in-class activity since model generation (in the cloud) can be time-consuming.

In addition to challenges faced in the activity, there were also lessons learned. File transfer proved to be a bigger issue than anticipated. Instructors intending to incorporate this activity are advised to use a good file sharing system. An additional lesson learned was in the trade-off between mapping a large area, requiring many photos, and mapping a smaller area that may be less impressive, but more manageable for students. Creating models of smaller areas requires fewer photos and ground control points, making it easier for students to navigate the process and likely improving the learning experience. Figure 2 depicts a portion of the study site consisting of one of the levees, a bike path, and a portion of the bridge. The sub-area shown in Figure 2 represents a more manageable in-class assignment for students. Perhaps instructors could have students create models of small sections of the study area while the instructor produces a larger, overall model.

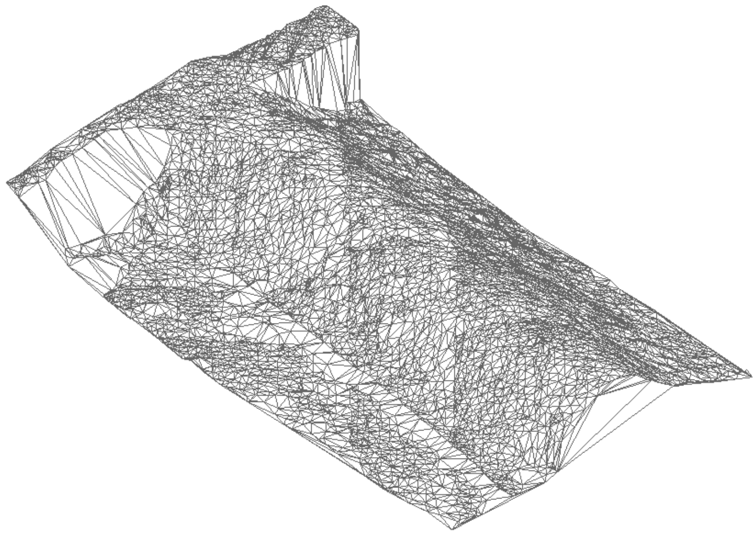

Figure 2. Three-dimensional model of one of the Calaveras River levees, created using 49 aerial images and four ground control points.

Conclusions & Future Work

In this study, we found that UAV technology could reasonably be integrated into the civil engineering curriculum. The construction engineering elective course was a good fit for this activity. Investment in resources was unnecessary as our institution had a UAV and a licensed drone pilot who was available to conduct the flight. Our institution also had the educational license for Autodesk products that provide a complete software suite for creating aerial photogrammetry maps using UAV images. We also had the surveying equipment needed to capture data on the ground control points. In general, having institutional support for technology is beneficial and this support should include investing in technology as well as maintaining it. The only significant investment was the time needed for the instructor to become trained in the process and in the equipment and software used in developing the 3D models. One aspect of this project that was particularly beneficial was having a cross-disciplinary team consisting of a civil engineering faculty and an electrical and computer engineering faculty. The civil engineering faculty was able to rely on the more technically savvy faculty member for support.

In this study, we found that UAV technology and mapping were readily accessible to the students. The field work portion of the activity worked well with the learning preferences of the students, who indicated (in a questionnaire) their preference for field work and work on teams. Students have an appreciation for learning new tools that are relevant to their interests and professional goals. Technology-based activities need to be carefully integrated into the curriculum, since students can lack familiarity and confidence in using technology. Learning new tools takes time and patience—for both students and faculty—and this reality should be considered when planning new activities.

Overall, integrating a new technology into the civil engineering curriculum was worthwhile and a feasible task for faculty. The students demonstrated capabilities in improving technology skill sets. Faculty and institutions must invest in learning and developing new technologies in order to make this effort effective.

Acknowledgements

The authors would like to thank Jeremy Hanlon for conducting the UAV flight and Jordan Baldwin for providing support in use of the surveying equipment. The authors also thank USDA-NIFA as this work was supported in part by USDA-NIFA 2017-67021-25924.

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CIVL 151 – Heavy Construction Methods, Fall 2019
Questionnaire, Pre-activity

I am working on a project to educate civil engineering students about relevant and developing technologies. This questionnaire is intended to collect information on how best to teach civil engineering students about technology. Participation in this questionnaire is voluntary and will not impact your grade in any way. If you choose to participate, please do not put your name on this paper. If you choose not to participate, please submit a blank paper (to remain anonymous). The questionnaire results will be compiled and used in a conference paper (American Association of Engineering Education).

1. Do you have experience using drones? Circle one: Yes No
   Briefly describe your experience:

2. Do you have experience making maps? Circle one: Yes No
   Briefly describe your experience:

3. Do you have experience with surveying? Circle one: Yes
   No
   Briefly describe your experience:

4. Do you have experience using electronics (e.g. sensors, instruments)? Circle one: Yes No
Briefly describe your experience:

5. Rate your comfort level in using electronics (e.g., sensors, instruments).

1 not comfortable	2	3 neutral	4	5 very comfortable

6. Rate your comfort level in using new software.

1 not comfortable	2	3 neutral	4	5 very comfortable

7. Rate your understanding of which technologies are used in industry.

1 not aware	2	3 neutral	4	5 very informed

8. Would you rather do field work or lab work? Circle one: Fieldwork Lab work

9. Would you rather work independently or in a team?
   Circle one: Independently Team

10. Any comments or thoughts regarding technology in education? Have you had any negative experiences using technology in educational settings?