AC 2009-2154: INCORPORATING VIRTUAL FIELD INFORMATION IN LEARNING CONSTRUCTION OPERATIONS

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Incorporating Virtual Field Information in Learning
Construction Operations

Abstract

Construction students must be equipped with both theoretical knowledge and hands-on experience for them to function effectively in the real world. One of the ways to expose students to the real world is to capture and share actual project information in a classroom setting. This study takes advantage of two of the recent developments in information technology for capturing and transferring real-world construction field data virtually to classrooms. These technologies include real-time, GPS-based construction equipment tracking and rapid 3-D modeling using digital photos and video data. The GPS system collects real-time construction equipment data from GPS sensors, and these data can be used by students to analyze construction productivity and design look-ahead schedules and to perform what-if analysis using computer simulation. The rapid 3-D modeling component allows users to transform a set of regular digital photos or video clips acquired from a construction site into an interactive 3-D model. Once the model is created, students can experience, on a personal computer, a 360-degree view of the site that can be used for effective visual presentation and communication, progress monitoring, and site layout planning purposes. The application of these technologies is demonstrated based on two industrial case studies.

Introduction

Construction management education is designed to prepare students of technical, practical, and managerial competence to implement the best practices and technologies in the construction industry. To achieve these goals, students must be equipped with both theoretical and working knowledge. Theoretical knowledge provides students with a precise and thorough background of all terms and conditions that explain the engineering and construction process. Meanwhile, construction is also a very practical field, and the most natural way of acquiring knowledge and experience is to be immersed in relevant situations and to practice. Therefore, in addition to book learning, exposure to the real-world construction and hands-on exercises are also essential for
construction education. However, students often have limited direct exposure to actual field operations due to logistic, cost, and safety issues associated with construction site tours.

A number of classical strategies can be used to fill the theory-practice gap in a classroom setting, including guest lectures, case studies, and classroom demonstrations. These methods provide students with examples of real-life problems and applications of modern management techniques. However, collecting and presenting a sheer amount of complex construction project data can be challenging. First, in order to better demonstrate and explain real-world phenomena, a large amount of accurate and comprehensive project data must be recorded and transferred to the classroom, and the time and cost required to do this manually can be prohibitive. Second, construction field data can be difficult for instructors to present and for students to comprehend due to the complex time and spatial relationships, the involvement of a large number of resources and activities, and the presence of numerous uncertainty factors. Third, collected project information is usually assembled and presented to students statically as a set of factual data. Although this customized information appears to be well-defined, it may not accurately represent the real-life scenarios that are usually semi-structured and open-ended. This data-sharing mode may discourage students from interacting with the data and diminish the opportunity to learn by doing.

With the recent advent of sensing, communication, and computer graphics technology, a variety of data collection and presentation methods are now commercially available for capturing and sharing real-world construction data. This paper describes an approach based on some of the recent developments in information technology to introduce construction field information virtually to a classroom setting. Specifically, two such technologies are studied at this stage of the project, namely real-time, GPS-based equipment tracking and rapid 3-D modeling using digital photos and video data. The GPS simulation collects real-time construction equipment data from GPS sensors, and these data are used by students to analyze construction productivity and design look-ahead schedules and to perform what-if analysis using computer simulation. The rapid 3-D modeling component allows users to transform a set of regular digital photos or video clips acquired from a construction site into an interactive 3-D model. Once the model is created, students can experience a 360-degree view of the site on a personal computer. The model can
thus be used for effective visual presentation and communication, progress monitoring, and site layout planning.

The paper is organized as follows. The following section provides a review of previous studies on capturing and sharing actual construction data for educational purposes. The two proposed technologies are then presented in two separate sections, each of which provides background information about the involved technology, types of data collected, and the usage of these data for student learning. These technologies are demonstrated through case studies on an asphalt hauling and paving project and a building project.

Background

To make an effective industrial case study, various types of project data from different sources need to be collected and later shared with students. After a case study is conceptually designed, required project data must first be acquired from actual projects in an efficient way. Depending upon the subject and purpose of the learning, data reflecting different aspects of a project may be needed, such as contractual data (e.g., contract and specification), product data (e.g., drawing and CAD model), process data (e.g., schedule, budget, and progress report), and situational data (e.g., claim and weather records). The scope of this study is limited to the collection of product- and process-related time and spatial data for learning construction operation management. After project data are collected and integrated, the data must be presented to students in a way that is easy to understand. This section reviews previous studies in both project data collection and presentation methods.

Historically, industrial case studies, especially those in the business domain, are summarized and collected in a written format. However, for construction education purposes, the written format fails to capture the visual aspects of the construction process, and it also makes data retrieval and analysis difficult. Many innovative methods have been introduced to capture and assemble project data in a digital multimedia format to support teaching needs. Potential raw data sources may include CAD models, labor expenditure data, progress reports, quality records, job diaries, site photographs, and videotapes. For example, time-lapse video can capture visually the
Chinowsky\textsuperscript{4} developed a prototype for an electronic library based on digital multimedia and Web-based technologies. The library introduced a structured approach to presenting case studies that provide students with illustrations of emerging civil engineering practices and regulatory compliance strategies. The prototype has a hierarchical architecture that is supported at the lower level with documents, images, and video clips. Navigation in the electronic library can be direct item viewing or sequential learning. With this structured approach of organizing project information, detailed construction operation-level data can also be collected and linked to other higher-level project data.

Traditionally, these operation data are collected manually, and the limitations of this manual data collection approach in terms of speed, completeness, and accuracy has been discussed in many previous researches.\textsuperscript{12} Advancements in field data-capture technologies such as hand-held computers, wireless communication, laser scanning, smart tags, and embedded sensors enable collecting, storing, and reusing field data accurately, completely, and in a timely manner.\textsuperscript{8} These technologies have been applied to collect a variety of construction project data that support many construction-management functions, such as productivity monitoring, supply chain management, condition assessment, and quality control. These project data, once integrated and associated with project time, represent a digitized version of the project execution history. This project history can have a multitude of uses, not only in supporting decisions throughout the lifecycle of a facility but also in advancing our knowledge and serving training purposes.\textsuperscript{2}

Another important aspect of delivering a case study is presenting potentially complex project data to students. The decision about how to present the data and how to maximize students’ learning experience can make a striking difference in the effectiveness of a case study. Static or dynamic data visualization can help students acquire new knowledge and skills more quickly than conventional presentation techniques. In addition to the traditional ways of using tables and charts to visualize data, computer graphics and visualization techniques provide even more creative and better data visualization solutions. 3-D CAD, which has been used extensively during the facility design stage can provide a free 3-D view of design details. In addition, 4-D CAD, which extends 3-D CAD with a time dimension, has steadily emerged as a project
planning and control tool. Recent development in Building Information Modeling (BIM) introduces an integrated method of generating and managing building data during the building’s life cycle. BIM also presents a great opportunity to integrate different types of project data such as time, cost, procurement, and quality records to a single 3-D building model. This integration strategy can greatly enhance students’ interaction with comprehensive project information.

The key to learning is motivation. A successful case study must also focus on motivating students by creating an immersive and interactive learning environment. Through engaging interactions and exercises, students can discover the facts of the case and apply their knowledge and skills to solve real-world problems. In particular, construction simulation and gaming provide students a simulated virtual environment in which they can collaborate, compete, and create synthetic solutions for various situations and problems. Numerous examples of using gaming and simulation to enhance construction education exist in the literature. This study is an ongoing effort in exploring and implementing new ways of utilizing real-world project data for construction education. The following sections describe two such applications in collecting and presenting actual project data.

**GPS-based Productivity Study**

*Productivity Study*

The first application is designed for learning productivity measurement, improvement, and project scheduling and control. Construction productivity is a fundamental piece of information for many construction-management functions. By definition, productivity is the ratio of the quantity of input, such as labor or equipment hours, to the quantity of the work output. Students must learn how to define and measure productivity and how to analyze the productivity data for cost estimating, project scheduling, and performance improvement. Typically, these learning subjects are covered in different courses and, therefore, students may not have the chance to fully integrate this knowledge and put it to work. A case study focusing on productivity monitoring and data analysis can put students in charge and engage them in utilizing productivity data for different management functions.
However, collecting and assembling a set of productivity data for such an exercise can be very tedious and time-consuming. One of the authors conducted a productivity study on an earth-moving project, and one objective was to collect productivity data for teaching purposes. Required data include resource allocation, excavator loading time, truck travel and unloading time. All data were collected manually by a team of four students at both excavation and dumping sites over a period of five days, which ensured that the impact of different weekdays and different periods of time during a day could be accounted for. This manual data-collection method is greatly limited by the availability of a sample project, as well as many other time, cost, and safety constraints. The collected data may also be less satisfactory due to recording errors and a relatively small data set.

With the recent advent of remote-sensing technology, a broad range of embedded, wide-area, and satellite-based sensors are now becoming commercially available, and these data-acquisition methods allow for wireless, automatic, or remote data gathering. This trend also means that real-world project data can be potentially transmitted to a classroom in near-real-time. Equipment-intensive construction projects have seen the use of the Global Positioning System (GPS) to track the real-time locations of construction equipment. GPS technology is used in this study to collect equipment productivity data. For this application, the industrial case study is in the heavy construction sector, and specifically in an asphalt hauling and paving operation. Heavy construction work is a highly equipment-intensive process and it usually spreads over miles. The asphalt operation involves producing hot-mix asphalt in a central asphalt plant and transporting the mix by trucks to the job site for paving. The application of GPS equipment-tracking technology can tremendously improve the data-collection process as discussed below.

**GPS Technology and Implementation**

GPS is a satellite-based navigation system that was developed by the U.S. Department of Defense (DOD) in the early 1970s. Initially, GPS was designed as a military system, but it was later made available to civilians and is now a dual-use system that can be accessed by both
military and civilian users. The GPS system consists of 24 operating satellites that provide continuous positioning and timing information for a vehicle equipped with a GPS receiver, and GPS-based location tracking has now become commercially available for monitoring heavy construction equipment, such as excavators, trucks, and pavers. A GPS receiver installed in a vehicle can determine its location, speed, travel direction, and time. In order to make this information available for remote, real-time monitoring, the data are transmitted constantly from the vehicle through a modem and a wireless cell-phone network to a central Web server. These data can be sent in real time or at a specified time interval, such as one minute.

The asphalt hauling and paving operation relies strongly on heavy equipment, and construction activities and events can be associated with the location, speed, or travel direction of equipment. GPS raw data can be analyzed manually to extract meaningful productivity data such as truck loading times and hauling times. This tedious data analysis task can also be semi-automated. To achieve this, knowledge regarding various events and activities involved in the operation must first be defined to assist data interpretation. To associate a truck’s location to a construction activity, a concept called “geo-fence” is used. A geo-fence, as shown in Figure 1, is an area that is defined around a fixed geographic location or a mobile object of interest, such as a paver. Geo-fences must be defined by project personnel for areas such as asphalt plant loading lanes and paver locations. For example, when a truck travels across the boundary and into an asphalt plant’s loading geo-fence, a start-loading event is logged, and when it moves out of the boundary an end-loading event is recorded. The time between start-loading and end-loading is the truck loading time. This semi-automated method can help students to analyze GPS data for productivity information.
Figure 1. GPS-based equipment tracking.

This application was made possible by the collaboration among the University of Houston, Heavy Construction Systems Specialists (HCSS), and Gilchrist Construction Co. HCSS is a software and hardware solution provider to the infrastructure construction industry in the areas of construction estimating, field management, and resource management. Gilchrist Construction is a heavy highway contractor based in Central Louisiana, and its projects include asphalt production and paving, concrete construction, bridge construction, pile driving, and excavation. HCSS’s GPS solution, which includes GPS receiver and wireless data transmission service, was adopted by Gilchrist. In addition, the contractor has a security camera system overseeing several key locations at the batch plant. The university reached a confidentiality agreement with the contractor to gain access to a selected construction project that involved grading, drainage structures, and asphalt concrete overlay for widening a two-lane highway to a four-lane highway, at a cost of close to three million dollars. Project performance data were collected from seventeen dump trucks and one paver, all of which were equipped with GPS.

Data Presentation
The sample project information and a description of the asphalt hauling and paving operation were documented in a video format, as demonstrated in Figure 2, for easy sharing with students. The equipment-tracking data were collected in real time and stored in a dedicated web server hosted by HCSS, and this server allowed end users to remotely view and query any real-time or archived tracking data in text format or animation. A picture of a truck travel-route animation displayed on an LCD monitor is shown in Figure 2.

Figure 2. Presentation of project data.

As mentioned previously, another important aspect of presenting a case study is to encourage student involvement. In this application, that means involving students and allowing them play with the data for productivity analysis and project planning. As soon as the data are gathered, many exercises can be performed, including productivity monitoring and improvement, cycle-time analysis, driver behavior analysis, and look-ahead scheduling. Figure 3 shows an analysis of truck cycle time and productivity analysis and a computer simulation exercise. Details of these exercises are documented elsewhere. The computer simulation exercise was found to be particularly useful. Students were involved in developing a process-simulation model with an easy-to-use graphical modeling tool based on their understanding of the construction operation and GPS-based productivity data. The model was also validated using archived project data.
data. Once established, the model enables students to conduct experiments in a computer format for what-if analysis, generating look-ahead schedules, optimizing number of trucks, and identifying ways to improve current performance.

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Cycle time and productivity analysis

Rapid 3-D Construction Site Prototyping

Background

Photography and time-lapsed video have long been used in the construction industry for project management and construction education purposes. In the last decade, digital imaging has gained tremendous growth due to its affordability and capability in capturing high-resolution images. However, these digital images represent the 3-D world in a 2-D format, and they are largely discreet and uncorrelated. Furthermore, these 2-D images may be taken from a myriad of viewpoints, camera settings, levels of detail, and lighting conditions. These issues make searching, synthesizing, and understanding a large amount of image data a challenging task.
Recent developments in image processing and computer vision have motivated many applications in the construction industry, including progress monitoring, quality control, and material management. One of the techniques, photogrammetry, provides measurement by analyzing a series of 2-D images of an object taken from different perspectives with matching features. The output from photogrammetry allows measurement and reconstruction of a 3-D model of the object. However, this technique normally requires manual matching of feature points in different images or attaching many identifying targets to the real-world object for automated pattern matching, which are both time-consuming to accomplish. Scanning by 3-D laser is an alternative method for capturing construction-site data in 3-D. This method involves the generation of geometrical properties of an object on site from the reflection of laser rays. The purpose of 3-D scanning is typically to create a point cloud of geometric samples on the surface of the subject, which can then be used to extrapolate the shape of the subject through a process called reconstruction. However, 3-D laser scanning-related equipment and software is very costly. Additionally, scanning constraints and extensive post-scanning data analysis also limit its usage.

This application was motivated by the recent development and applications of Photosynth, a computer vision program promoted by Microsoft Live Labs. This data-collection and presentation method was adopted here for modeling construction sites. It can rapidly capture and transform a set of regular digital photos or video clips acquired from a construction site into an interactive 3-D model that allows students to explore.

*Photosynth and Its Application in Construction*

Photosynth is a software application that analyzes digital photographs and generates a 3-D model of the photos and a point cloud of a photographed object. The system allows users to interactively browse and explore large, unstructured collections of photographs of a scene using a novel 3-D interface. To achieve this, Photosynth first analyzes multiple photographs taken from the same scene for common feature points and based on these features, photographs are compared and matched and a 3-D model of the scene is constructed. This entire process is
achieved using an algorithm based on the concept of “interest-point detection” and a matching algorithm. After the photographs are matched, a graphical Web-based user interface is used to display the 3-D model, and the interface also allows users to navigate through the 3-D model or point cloud of features. Photosynth’s image-based rendering technique provides a smooth transition between photographs while also enabling 3-D navigation and exploration.

Photosynth provides some general guidelines on shooting effective photos for better photo recognition and synthesizing rate. It is important to ensure that each part of the target object appears in at least three separate photos taken from different angles and locations. This means that many more photos are required for a Photosynth than would be required for any other purpose. Photosynth recommends a large photo overlap rate of at least 50% to achieve better results. When moving around an object, it is suggested that photos be taken every 25 degrees or so. For shooting interiors, 15 to 30 photos may be needed to go all the way around. For shooting a 3-D object, it is important to obtain considerable overlap around an object and to walk around it. Finally, if particular details of an object are desired, users should zoom in on the area of interest gradually and take several intermediate images while zooming in. These intermediate images help Photosynth to accurately capture the location of the interested area and its relationship to other portions of the scene.

At this stage of the project, a small commercial building project was identified for data collection, and more than 1,000 photos and video clips were taken from both the exterior and interior of the building. The objective of this pilot study was to test the performance of Photosynth using digital photos and video clips. Meanwhile, it was intended to provide better understanding of factors related to photo shooting, which may directly affect Photosynth’s performance.

Collected photos were uploaded into the Photosynth Web site, and the uploading time is largely dependent on the file size of the digital photos. The matching and image-rendering operation occurs at the Photosynth’s central server, and the matching rate can range from as low as 5% to a high of 100%, depending upon the quality of the photos and the complexity of the scene. Specifically, the project evaluated several factors during photo shooting, including overlap rate,
image resolution, lighting, and the use of video clips. Some of the observations are summarized below:

1. **Overlap rate.** Although overlap rate does affect the matching rate, as indicated in Photosynth’s guidelines, another factor—the amount of overlapping features between pictures—is also important. The more common features two photos share, the easier is the matching process.

2. **Image resolution.** Photosynth can be used with images of different resolutions. However, our experiments showed that image resolution has a major impact on the matching rate. As the resolution is increased, a higher matching rate can be achieved.

3. **Lighting.** The amount of light was also shown to be an important factor. Matching rates tend to be higher for photos taken under daylight. For indoor applications, camera flash can compensate for low light, but due to its relatively limited coverage, much of the background is still relatively dark, which tends to lower the matching rate. Better lighting indoors (e.g., stand-alone lights or flash umbrella reflectors) may improve the results.

4. **Video clips.** A video clip is essentially a large group of correlated pictures, and the advantage is that it is easy to collect. In addition, by shooting a video, the time required to capture various respects of a scene can be effectively reduced. While these were the expected benefits, the actual result from this study was not very fruitful at this time. This may due to the fact that a movie involves objects that may be in motion and the resolution of a video image is usually much lower compared with that of a static photo. More experiments with high-resolution video cameras and different video shooting factors need to be conducted in the future.

Once the photo matching is completed and a 3-D model is created in Photosynth, students can experience a 360-degree view of the site on a personal computer. Figure 4 shows screenshots of the model created from the sample project photos. This model can be used for effective visual presentation and communication, progress monitoring, and site layout planning purposes. Students can freely navigate within the model to inspect details, such as a structural connection and detail finishes. The point-cloud data can be displayed in a 3-D space, and, alternatively, the
data can be exported to a 3-D modeling tool for further rendering for site layout analysis. These usages of the data will be further explored in our future research.

Conclusions

Students’ exposure to real-life case studies can stimulate their creativity and foster critical thinking. Real-world project data contain actual project conditions and performance information, which can be effectively used for learning purposes. However, the collection of such actual data can be challenging due to the complex nature of project data, the availability of sample projects, many time and cost constraints. This study proposes two effective methods for capturing and transferring real-world construction field information virtually to classrooms. These technologies include real-time, GPS-based construction equipment monitoring and rapid 3-D modeling using digital photos and video data. The GPS-based tracking technology automates the data collection process, and it makes productivity data extremely easy to access virtually from anywhere. The productivity data can be used to actively involve students in hands-on exercises through interactive computer simulation experiments. The 3-D modeling approach based on computer vision concepts introduces an efficient way to rapidly capture spatial data in digital images and later transform these images into an interactive 3-D model. This model provides students with a 360-degree view of a construction site and the capability to navigate and investigate construction details. Future research effort will focus on enhancing the usage of the proposed technologies as well as identifying new data acquisition technologies to serve classroom learning needs.
Figure 4. Matched photos and 3-D point cloud in Photosynth.

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