Novel Technologies for Construction Field Data Collection

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Summary

A vast growth of advanced information technology systems and tools nowadays is opening new ways to collect accurate as-built data. Since the turn of the millennium, new technology developments enable for the first time to gather accurate as-built information. Accurate as-built data will be of great usage to construction management as well as to designers and engineers. Given that most of the planned data are already digitally available, as-built data remains on paper forms. Information technology developments are opening new ways to digitize construction field data in order to develop intelligent tools for construction management allowing design engineers to update as-planned data. 3D Laser scanning, digital close-range photogrammetry and mobile computing are among the promising data collection technologies, which are auspicious to create new opportunities to develop advanced construction management and engineering tools. Primarily, accurate collected as-built data will be highly beneficial for the process of updating as-planned data.

1 Introduction

Automating construction field data collection is one of the most promising areas of intelligent job site research. One cannot overemphasize the importance of accurate construction jobsite data. The progress of construction activities and the utilization of resources, such as labor equipment, and materials must be documented accurately to provide teams timely information for making decisions. Most construction jobsites today, however, operate at a mode of T+3, T+7 or T+14 days, meaning that complete project data will become available after 3, 7, or 14 days. While the effort of collecting data is on going, more events happen, costly resources are committed, or, even worse, field mistakes continue without corrective actions. The reasons for these time lags vary from organizations involved and the tools used in collecting field data. For a reasonable-size construction project, there are approximately 50 to 100 subcontractors, ranging from a few hundred to several thousand workers on site daily. Many projects now collect and update jobsite data on a weekly or biweekly basis to coincide with payroll or payment processing. Although weekly or biweekly data update cycles may seem adequate for some companies, there are documented cases that many costly rework or mistakes could have been avoided had the data collection cycle been shorter and more timely. Timely project data not only allow project managers to react and fix problems quickly, but also enable them to predict potential problems so that mitigating measures can be taken.

Several advances in information technology have made possible new approaches to collect timely construction field data, such as project progress, manpower, resource utilization, safety, and productivity. Among these advances, three existing technologies are gradually changing how jobsite data are collected and managed. (1) wearable and mobile computing, (2) 3D laser scanning, and (3) webcam-based digital close-range photogrammetry. Wearable and mobile computing includes hand-held and wearable computers that allow project engineers to enter project data directly to a database via wired or wireless communications. 3D laser scanning technology utilizes LiDAR (Light Detection and Ranging), which uses laser (light) to beam at objects and obtain their dimensions. From the dimensions, quantity and productivity data on construction progress can be extracted. With the popularity of digital cameras and the convenience of the web access, many job sites now have webcams for project participants to view construction progress. A promising development is to utilize those images with photogrammetry tools.

This paper presents (1) the field-tested experience of mobile computing, 3D laser scanning, and webcam digital close-rage photogrammetry, and (2) a vision of field data integration to fully support intelligent jobsites of the future. This paper is organized into four main sections. The first section describes the challenges and needs of field data collection in jobsites, followed by discussions of promising advances in IT that may improve jobsite data management. The third section is devoted to other related technologies such as sensors RFIDs (Radio Frequency Identification) and GPS (Global Positioning Systems). The last section will conclude the findings of the field test and suggest future research directions.

2 Needs and Challenges on Field Data Collection

With increasing complexity of construction projects and increasing budget and time constraints, field data collection becomes more and more of a significant importance. Nowadays, construction progress reports still rely heavily on the experience of construction personnel. On weekly basis, construction management meets and analyses project progress in order to update existing planning. In worst case new planning action has to be taken to meet project goals. Changes made, are often poorly recorded. Some mistakes are even left disregarded. During the entire execution phase of a construction project, most of data collection is done through forms, filled out by construction personnel. In addition, construction management keeps track of construction activities in a daily log. Efforts in construction field data collection are done manually. Data collected by hand is known as to be exceedingly error prone, hence inaccurate, not to mention vastly time consuming. Nevertheless, construction progress data is vital to support construction management decision making as well as to allow managers to react to changes as the projects is being under execution. One cannot underestimate the importance of as-built data to construction project participants. Particularly in the construction industry, where prototypes are costly, engineers, designers and construction management are reliant on accurate as-built data. If construction progress data is collected precisely, personnel in charge are able to make appropriate decisions in order to successfully manage equipment, material, labor, time, budget and scope. Figure 1 illustrates the influence of construction field data collection. Field data collection, mainly conducted throughout the execution phase of a construction project, also benefits the two other phases of a construction project. First, collected as-built data can be used to update as-planned data. This feature will enhance construction project management and control tremendously. From early stages of a project, schedules for examples can be updated as construction is being undertaken. Field data feeding improved data analysis tools will provide construction managers and engineers proactive capabilities, enabling them to react to changes rapidly and efficiently. Secondly, accurate field data collection will also profit the operation and maintenance phase during the lifetime of a project. Project databases will enable access to construction data. IT based systems for monitoring buildings (Foerster and Diaz, 2001) able to access a generated project database to upload and retrieve operation and maintenance relevant data. Further, embedded data collection technologies such as sensors will provide operation and maintenance data throughout the lifetime of a building. Thirdly, field data collection will provide a detailed project database to apply data mining technologies in order to discover knowledge. Generating knowledge from large construction databases (Soibelman and Kim, 2000) will be the key to improve future planning of construction projects.

Many new developments in information technology have opened new possibilities to collect construction field data in a timely manner. Along the vast growth of developments in the information technology sector, researchers (Hwang et al., 2003) are exploring new applications for real-time 3D field data collection. Among those technologies, three-dimensional laser scanning, digital close-range photogrammetry and mobile computing prooved to be of great advantage to collect accurate as-built data. 3D laser scanning enables collection of accurate spatial information of objects being build. Accurate information about seizes of an object can easily be extracted. Digital close-range photogrammetry is a less expensive way to collect accurate spatial information, also providing digital images for construction progress documentation. Mobile computing mainly assists in manual construction field data collection with the advantage to store collected data directly to a project database. For several years, researchers at the University of Illinois have conducted various tests using these technologies. These tests showed both, advantages and challenges to integrate various technologies at the job sites.

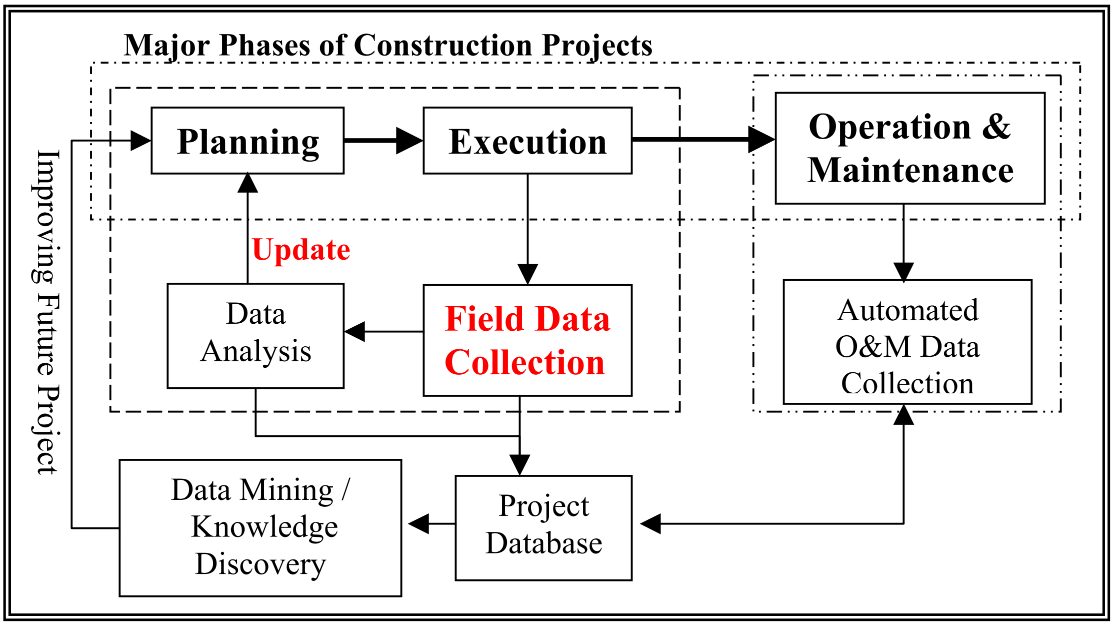

Fig. 1: Data Collection Cycle

The following sections introduce these technologies and show the results of ongoing field tests, posing the envelope for challenging new information technology developments for the construction environment.

3 Advanced Data Collection Technology – Field Tested

3.1 Mobile Computing

Handhelds and wearable computers are gaining more popularity in the construction industry. They are used not only to access project information but also to collect field data, such as manpower and project progress. Many handheld computer manufacturers offer attachments such as digital cameras and digital recording sound, making these handheld computers useful tools for collecting multimedia project data. There are three general categories of mobile computing devices available: PDA's (personal data assistants), wearable computers and tablets PC's. PDA's are handheld computers, such as Palm or Pocket PC's, capable of collecting field data into databases. They are small and relatively inexpensive, at $300-$800, running operating systems such as PalmOS and PocketPC. These hand-held computers are considered companion devices that can dock and synchronize with a PC computer to upload or download data. Newest technology even provides wireless synchronization. Wearable computers are customized industrialized PC's with a heads-up display which allows hands-free operations. Some include voice recognition and command operations. Tablets PC's have the size of a laptop computer with a touch-sensitive screen and handwriting capabilities. Weighing 2-4 lbs, these tablets PC's allow field personnel to enter data on electronic forms as if they were writing on a paper form.

Many researchers have contributed to field data collection using mobile computers by developing various hardware and software. Among them, Garrett (1998) designed Mobile Inspection Assistant (MIA), a wearable computer, for bridge inspection applications. Buergy (2002) already described interfaces between humans and smart infrastructure systems to enhance operation and maintenance of large-scale construction projects. Liu (1997) developed the digital hard-hat system for construction documentation and collaboration. De La Garza (1998) explored wireless communications and hand-held devices for tracking construction schedule. These endeavors have led to new developments as a result of IT advances, especially in the areas of computer hardware, software, and communications.

In order to test this, technology equipment was deployed at a construction site to evaluate realistic behavior of the new mobile computing developments under practical conditions. The field trial proved capabilities, which are promised by product specific information. Deviations are emphasizing even more the difficulties of mobile computing in construction management. Latest developments of new mobile computing technology are not entirely ready for employment in the field of construction, but are shortly before it. A new generation of portable computers as well as faster communication technology will force the breakthrough of mobile computing in the construction industry.

3.2 3D Laser Scanning

Three-dimensional laser scanning is a new technology in the field of surveying that allows measurement of a large number of points in a relatively short amount of time. It is possible to gather spatial data including all geometric information's needed to construct a three dimensional model of an excavation site for example. A 3D laser scanner is able to measure millions of points, within their exact 3D location. Even though lasers have been used for years (e.g. barcode) they are rapidly changing the surveying field and the construction industry for collecting site data. The basic technology of laser scanning (measuring with light) is called LIDAR (Light Detection and Ranging). It is similar to RADAR (Radio Detection and Ranging), but it uses light to measure range or distance precisely. Based on the information on the size or shape of the object being scanned, distances can be determined. Laser beams consists of an emitting diode that produces a light source at a very specific frequency. A mirror directs the laser beam (with a diameter of 6mm) horizontally and vertically towards the target. The surface of the target then reflects the laser beam. Using the principles of pulse time of flight the distance can be determined by the transit time, with a precision of +/- 6mm. The result of a scan produces point clouds, which can be processed into accurate 3D models.

Researchers around the globe are working on implementing three dimensional laser scanning technologies for the construction industry (Wunderlich, 2002), (Kern, 2002). Successful volume calculation using 3D laser scanning has been conducted in a lab experiment at the National Institute of Standards and Technology (Stone et al., 2000). Three-dimensional laser-scanning systems provide new opportunities for collecting accurate construction field data in the Architecture/Engineering/Construction industry. Scanned data produce accurate as-built information for project control and analysis. This accurate as-built data opens new possibilities for analysis and feedback on a number of construction management issues as well as on engineering design.

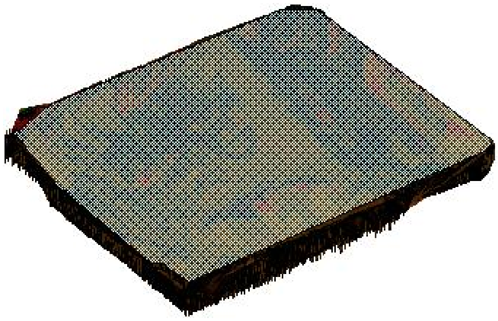

Fig. 2: Volume Calculation (33,456 m^3)

A research team at the University of Illinois and Northwestern University conducted a field trial of 3-D laser scanning at the Lurie Research Center excavation project in downtown Chicago. A Cyrax 2500 laser scanner, from Leicageosystems Inc., was used to carry out the field trial, whereby each scan consisted of 1 million points.

A total of 16 scans from three locations were conducted during the excavation process. It took approximately six hours to scan the entire construction site, which measured roughly 255ft x 225ft x 25ft (length x width x height). After scanning the entire site, the collected data was processed through a software program, called Cyclone from Cyra Inc. The scans were then registered ("stitch") together to produce a single to-scale 3-D image of the site as shown in Figure 3.

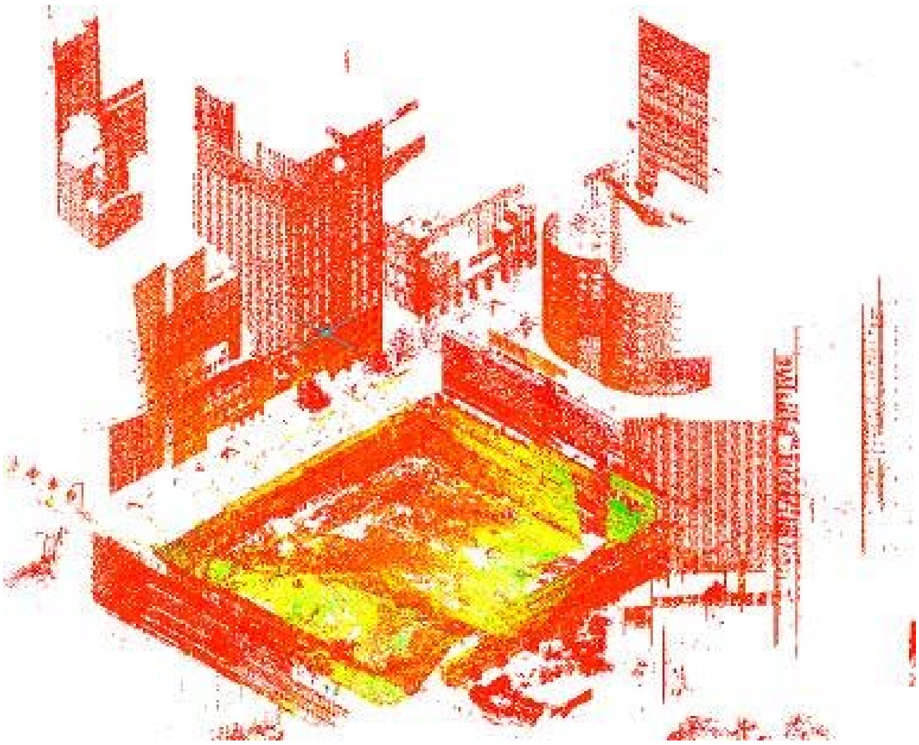

Fig. 3: 16 Scans Registered

The scanned data can be cleaned to remove extraneous objects such as surrounding buildings or earthmoving equipment. In this trial, the focus was on measuring the volume of the excavated material. Hence, surrounded buildings as well as obstacles inside the excavation were deleted, which resulted in a point cloud describing precisely the surface of the terrain. This surface was then used to generate a mesh. A mesh was used to represent the surface topography from the previous scanned and processed point clouds. A reference horizontal plane was placed at the ground level to compute the total excavated volume. The space enclosed by the surface of the terrain and the plane describes the volume of the excavated earth. The volume can be calculated by integrating the distance between the plane and the terrain surface as illustrated in Figure 2, with a total volume of 33,456 cubic meters.

Digital Close-Range Photogrammetry

Photogrammetry has been used in various applications from aerial survey to military intelligence. Using photos taken from different angles of an object, photogrammetry techniques can extract 3D data. One of the most popular photogrammetry applications is in the fields of archaeology and architecture. In both areas, photogrammetry is used to document archeological excavations or facades of historical buildings in need of renovation. In particular, some photogrammetry systems in architecture generate three-dimensional models of buildings including texture mapping.

Digital close-range photogrammetry is a measurement technology used to obtain three-dimensional (3D) spatial information about an object or a construction site. This technology derives measurements from digital images of the object, rather than measuring the object directly. At close-range, digital cameras are positioned within approximately a 100-meter range. The cameras can acquire images from multiple positions around and within an object. Digital close-range photogrammetry is suitable for a large number of applications, ranging from simple manual control point measurements to automated processing covering zones of large spatial extent.

Digital close-range photogrammetry (DCRP) has various potential applications in construction. They include accurate as-built dimensional data for remodeling, quality control of building dimensions, and monitoring distortion and displacement of structures. Research done at the University of California at Berkeley, as well as at the Technical University of Berlin, already demonstrated the potential of automated photogrammetry systems for recording and document historical buildings (Debevec et al., 1996), and (Wiedemann and Rodehorst, 1997). Further, digital close range photogrammetry has been used in structural tests in order to record and measure cracks in concrete during laboratory tests (Whiteman et al., 2002). Figure 4 shows a test of DCRP to capture the geometry of a structural test at the Newmark Laboratory of the University of Illinois at Urbana-Champaign. Digital images were acquired from five different locations and processed into a 3D model.

Finno (Finno, 2003) used a web cam to monitor the construction progress at an excavation site in downtown Chicago. The web cam provided 2-D digital images of the site in addition to live feeds of construction activities. The authors of this paper are currently extending the use of web cams for use with digital close range photogrammetry (WDCRP). In WDCRP a number of high quality web cams can be installed around a construction site. These cameras will deliver digital images in set time interval; using DCRP these photos can be processed to generate volume or profiles of an excavation site. This system will permit the acquisition of dimensional data related to excavation geometry remotely and in a timely manner. We are currently exploring the various issues associated with deploying such a system in the field

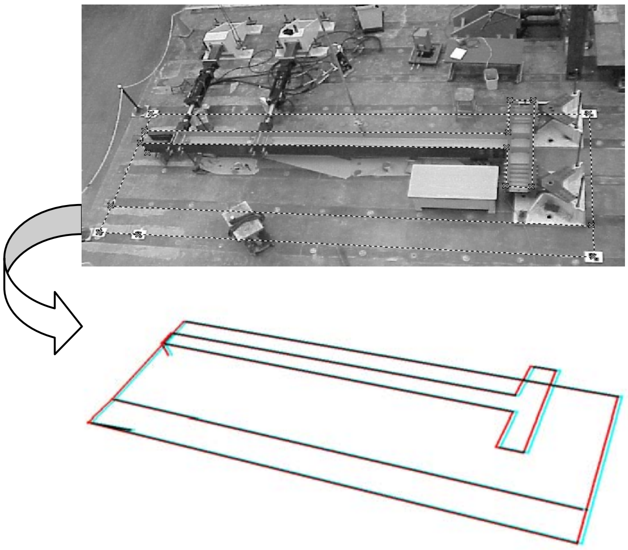

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Fig. 4: DCRP – Three-Dimensional Model Generated from Digital Images

4 Radio Frequency Identification (RFID) and Global Positioning System (GPS)

RFID systems consist of two major components, the reader and the tag. RFID tags are small transponders, which offer data storage capacity like a barcode. They can be accessed and edited by a reader through radio frequency without a line of sight. Attached to building components, it allows construction personnel to track their history; from leaving the factory to their installation. Jaselskis (Jaselskis and El-Misalami, 2000) utilized Radio Frequency Identification (RFID) to track and collect data for construction materials. Information of different construction components can easily be stored in the project database and used in connection with other construction field data collection technologies in order to document their history.

GPS, global positioning system, is a radio navigation system that allows its users to determine their exact location, 24 hours a day, in all weather conditions, and anywhere around the globe. In total 24 GPS satellites are orbiting the earth. These satellites are spaced, so that at any point on earth, minimum four satellites are on the horizon. The GPS receiver on earth receives signals broadcasted from the satellites. With the changing position and their time, the receiver can triangulated its exact position, resulting in longitude and latitude. Sacks (Sacks et al., 2003) used this technology successfully to monitor labor movements on a construction site. GPS technology enabled to measure workers locations precisely.

The above shortly introduced technologies complement modern data collection technologies, providing the capabilities to track labor and material locations. In connection with actual produced output, measured with a three-dimensional laser scanner for example, real-time productivity can be calculated.

5 Future Vision

The future of modern data collection will primarily be divided into two major parts. First, it will be automated data collection, without user interaction. Construction field data would be collected, while accessed and processed from remote locations. The technology equipment for this purpose ranges from fixed installed web cameras or three dimensional laser scanners to sensors and RFID-tags. The other part will mainly benefit from active data collection.

Construction personnel will be able to collect data manually, assisted by advanced data collection technology, such as mobile computing. Both ways of data collection will merge into a project database, where collected data will be accessed, analyzed and processed. A project database as the heart of data collection will serve multiple purposes. As drafted in figure 1, the project database will be the origin for multiple methods to improve current and future construction projects. Once accurate data is collected it will enable us to develop tools, which will assist construction managers in updating construction data, assisting in making decision to meet project demands. However, data collection is by far not limited to a single ongoing construction project. With input from ongoing construction processes as well as from the lifetime behavior of a building, the project database opens tremendous opportunities for future research. Engineering research already demands accurate as-built information (Hashash et al., 2002), to enhance engineering analysis tools. Modern data mining methodologies will enable to detect relationships between different construction projects, resulting in developing new project management and proactive control approaches. At any rate, collecting accurate as-built field data still remains extremely challenging. One single tool will not deliver all desired results. An integrated system, integrating the technologies presented in this paper remains to be developed.

6 Conclusion

The tested technologies demonstrated the feasibility of collecting accurate construction field data. However, each technology in their own will not lead to successful data collection systems. An integrated system, which combines all of the above-introduced technologies, will provide a practical tool for assisting construction management in successfully managing equipment, material, labor, time, budget and scope. Further, field data collection will provide great conditions for data mining to improve the planning and execution of future construction projects. However, one of the key challenges is the data integration problem. The existing data integration is limited to data retrieval and organization. There exist a great opportunity to design and implement data integration among various technologies to fully support advanced data analysis and knowledge discovery, such as identifying cause-effect relationships among factors causing low productivity and poor construction quality. In order to provide such integration, new standards must be developed to support the data lifecycle of collection, storage, analysis, and retrieval. Nevertheless, the major challenge is still left on the practical side of automated data collection. Even though, modern technologies are capable of delivering desired results, they remain to be field proven. Not only one at a time, a system combining these technologies would promote these research efforts enormously. Having this in mind, three key players have to work closely together. Researches have to develop novel methodologies to process and analyze collected data. Technology developers ought to provide newest released equipment while the third party, the contractors, are supposed to grant unlimited construction site access and document sharing. Realizing this, construction field data collection will soon experience a vast breakthrough. The construction execution phase will not remain paper based and will generate great opportunities to various research disciplines such as data mining and engineering analysis to conduct further research.

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