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Automated progress control using laser scanning technology

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ABSTRACT

Assessing progress in construction activities is time consuming and requires the use of specialized personnel. Automated progress control could reduce the workforce, the cost, and the time used, reduce disagreements, and add to the overall efficiency of project management. Attempts have been made in the past to resolve this issue using image processing and other techniques but the results have not been satisfactory. A new attempt is now made to set up a system that can assess progress control with minimum human input. An experiment makes use of laser scanning technology. The initial results appear to be promising but there are still obstacles to surmount. The system is robust and accurate in laboratory conditions and constitutes proof of concept. Improvements are necessary to accelerate the registration process of multiple scans, to recognize objects of irregular shape, and to assess the practicality and economic feasibility of such a system.

1. Introduction

Construction progress control is a critical task in project management. Traditionally, construction managers walk around in the construction site to verify progress in different activities and understand the current status of the project. Current progress control is time consuming, requiring data collection and extraction from construction drawings, schedules, and budget information [35]. The quality of progress control depends on the quality of the inspector's field reports, which may sometimes contain entry mistakes. The quality of manually collected and extracted progress data is typically low [18]. Over the years, attempts have been made to streamline this process by using advanced computer technologies. For example, Abeid and Arditi [4] developed an automated real-time monitoring system that links time-lapse digital movies of construction activities, the critical path method (CPM), and visual progress control techniques. It enables managers at the contractor's and the owner's headquarters to follow developments at the construction site in real time. Zhang et al. [34] explored the potential of using computer vision technology in assisting project managers with determining the progress of construction from digital images captured on the site. The study focused on the quantity rather than the quality of the work and was limited to the superstructure of buildings. Gordon et al. [21] presented the details of an automated planning approach to support on-site construction inspections and thereby allow inspectors to both generate complete, detailed inspection plans and to consider numerous possible alternatives in detail.

Several researchers experimented with different imaging techniques to produce essential construction management information in an effective manner. For example, Abeid et al. [7] developed a method for recognizing the presence of a structural component in a digital picture taken at a construction site through the component's color and position. Abdel-Qader et al. [2] compared diverse image processing techniques and chose a series of techniques that work best for the identification of cracks in a bridge component. By combining image processing techniques and a database of construction materials, Brilakis and Soibelman [13] used a shape retrieval mechanism to recognize a range of construction material resources. They also used 3D imaging techniques to analyze construction project processes. Quinones-Rozo et al. [25] applied image processing techniques to quantify excavation progress. Golparvar-Fard et al. [18,19] proposed automated methods for progress monitoring using photographs taken from a construction site. Tang et al. [29], surveyed techniques developed in civil engineering and computer science that can be utilized to automate the process of creating as-built BIMs. Gong and Caldas [20] developed and evaluated several vision-based construction object recognition and tracking methods for construction video analysis. Walia and Teizer [32] simulated the processing of location data for collision detection and proximity analysis and demonstrated that real-time proximity detection of resources is feasible.

Most research on automated project progress control aims to measure the physical quantities in-place by using spatial sensing technologies [30]. However, these methods are mostly based on immature technologies, are cumbersome to use, and require frequent and constant manual intervention. Methods need to be developed that are not only easy to use, but are also based on mature technologies that have proved to be of value in day-to-day construction operations, such as laser scanning.

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Laser scanning is gaining increased recognition in civil engineering applications. 3D laser scanning is a relatively new surveying technology that captures the real scenery and translates it into a 3D virtual world. It utilizes light detection and ranging to produce accurate 3D representations of objects. A laser scanner consists of an emitting diode that produces a light source at a specific frequency. A mirror directs the laser beam horizontally and vertically towards the object. The surface of the object then reflects the laser beam. Using the principles of pulse time of flight, the distance to the object can be determined by the transit time. The result of a scan produces a collection of points in space, commonly known as "point clouds," which can be processed and combined into accurate 3D models [28]. The density of the points depends on the speed at which the laser travels the surface. A laser scanner can provide a fast, good quality and precise analysis and feature detection of any object.

Recently, more and more scholars picked on the laser scanning technique to monitor their construction project. For example, Hashash et al. [22] used laser scanning for predicting, monitoring, and controlling ground movements associated with excavations in urban areas. Walters et al. [33] developed a system that determines the thickness of a pavement in real time by laser scanning the surface of the subgrade prior to paving, and then scanning the surface after paving. Shih et al. [27] made a point-cloud-based comparison between as-planned and as-built progress schedules. Arayici [8] used a scanner to digitize all the 3D information related to real world objects such as buildings, trees, and terrain down to a millimeter of detail to facilitate the refurbishment process in the built environment. Walters et al. [33] used laser scanning to define the thickness of a concrete pavement. Bosche and Haas [10], Bosche et al. [11,12], and Turkan et al. [30] obtained promising results of progress monitoring using a 3D laser scanner and a simple 3D model. Cheok et al. [14,15] assessed and documented the construction process in real-time on the basis of 3D as-built models by using laser scanning technology. Randall [26] analyzed the construction engineering requirements of laser scanning technology for applications across all phases of the project life cycle and proposed a multidisciplinary framework to integrate applications of laser scanning technology with the fundamentals of three-dimensional model-based design.

The objective of this study was to develop an automated progress recording system that does not require any periodic human input measured by a professional either at the construction site or from photographs. In this research, data was obtained by using a laser scanner. A registration process was performed to combine different scans and obtain point clouds. A 3D model of the project that was developed earlier was superimposed on the point clouds. The volume of work completed was compared with the volume of work expected, and a percentage of progress was obtained. This new progress measurement method automatically calculates the percentage of completion of a construction activity.

2. Methodology of the study

This section describes the steps adopted in this study to capture, process, model, and integrate 3D laser scanner data about a construction process. The flowchart of the steps is presented in Fig. 1.

2.1. Design of a 3D/4D model

First, a 3D model of the structure is developed and the activities of the project are defined, using a 3D modeling software, such as MicroStation, Revit, or ArchiCad. For example, as was done in this study, the volume/surface area of the objects involved in each activity can be calculated by MicroStation V8i using the object's 3D coordinates. The same approach may be used if other software programs are used in developing the 3D model. Finally, using the facilities provided by Navisworks, a work schedule is linked with the 3D model making it a 4D model.

2.2. Capture of point cloud data

3D point cloud data is captured using a laser scanner that comes typically with its own software. There are two different types of scanners that are commonly used in 3D laser scanning. *Phase-based scanners* utilize a constant beam of laser energy that is emitted from the scanner. The change of phase of the laser light is measured to allow the scanner to calculate distances. Phase-based scanners are typically used in industrial applications or interior architectural spaces to populate detailed building information models of existing facilities. The advantage of this technology is the significant speed of data capture. It can capture hundreds of thousands to millions of 3D points per second, which is approximately ten times faster than most time-of-flight scanning systems. Thus, the Leica HDS 6000 laser scanner that was used in the laboratory experiment represents an appropriate selection. The major limitation of phase-based-scanners is a short range, but this limitation does not preclude its use in progress monitoring applications like the system proposed here. *Time-of-flight scanners* emit a pulse of light which measures the amount of time it takes to travel from the scanner to the object and back allowing the scanner to calculate the distance. The key benefit of this type of laser scanning technology is its long range. But these scanners can collect fewer points per second compared to phase-based scanners. Time-of-flight technology is typically used for topographic surveys of roadways and as-built structures.

First, the positions of the scanner in the construction site are decided. For a realistic representation of the object, a scanner is positioned in several locations and the object is scanned from different lines of sight. The scans are merged using the registration process and all the points on the object (not only those facing the scanner) are captured.

2.3. Registration and integration of the 3D model with point cloud data

Registration is the process of integrating several scans into a single coordinate system. This process involves using a system of constraints, which are objects that are placed at the same location every time a scan is performed. The registration process performs optimal alignment transformations to make sure that the targets used as constraints are aligned as closely as possible. Registration can be performed by commercially available independent software or by software provided by the manufacturer of the laser scanner, such as a program called Cyclone provided alongside the Leica HDS 6000 laser scanner that was used in this study.

After registration, the coordinates of all points are stored in a file that includes four columns of information that involve a point's ID number and its x, y, z coordinates.

In order to integrate the 3D model with point clouds, the 3D model is converted into a format that is compatible with the requirement of the software that handles point clouds. The coordinate system of the 3D model is set to correspond exactly to the coordinate system of the point clouds, and then the 3D model is superimposed on the point clouds.

2.4. Object definition and progress measurement

In the scan data, there are numerous points, including many points that are not related to the object under consideration. So, if the objective is to monitor the percentage of completion of an object, the points associated with the object need to be extracted from the original data. A java script was developed to count the number of points in the related portions of the point clouds. To account for construction and laser scanner tolerances, the true coordinates of the object in the 3D model are augmented by 0.7% increasing the volume of the object by 2% following [36] observation