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Towards an automated photogrammetry-based approach for monitoring and controlling construction site activities

Hany Omar[a,*], Lamine Mahdjoubi[a], Gamal Kheder[b]

[a] Department of Architecture and the Built Environment, Faculty of Environment and Technology, Frenchay Campus, Coldharbour Lane, University of the West of England, United Kingdom
[b] R&D department VirtualProjects, Cairo, Egypt

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ABSTRACT

The construction industry has a poor productivity record, which was predominantly ascribed to inadequate monitoring of how a project is progressing at any given time. Most available approaches do not offer key stakeholders a shared understanding of project performance in real-time, which as a result fail to identify any project slippage on the original schedule. This paper reports on the development of a novel automatic system for monitoring, updating and controlling construction site activities in real-time. The proposed system seeks to harness advances in close-range photogrammetry to deliver an original approach that is capable of continuous monitoring of construction activities, with progress status determined, at any given time, throughout the construction lifecycle. The proposed approach has the potential to identify any deviation of as planned construction schedules, so prompt action can be taken because of an automatic notification system, which informs decision-makers via emails and SMS. This system was rigorously tested in a real-life case study of an in-progress construction site. The findings revealed that the proposed system achieved a significant high level of accuracy and automation, and was relatively cheap and easier to operate.

1. Introduction

The majority of construction projects tend to suffer time and cost overruns. According to Companies' public annual reports (2013) 98% of projects experience an average slippage of 20 months behind original schedule, and an average cost increase of 80% of original value. These overruns are associated with a failure to deal with loose control on projects, which are often brought about by poor project management strategies and old fashion technologies [1,2]. The conservative nature of the construction industry tends to cling to ineffective monitoring and controlling systems, which has severe consequences on the speed and robustness of decision-making [3,4]. The prevailing monitoring systems suffer from various inefficiencies that fail to detect potential delays. In addition, they do not have the ability to collect accurate data to reflect the correct as-built site progress status [5].

Despite recent advances, the prevailing monitoring and management systems in the construction industry are still dominated by traditional approaches, including manual paper-based collection and recoding of on-site activities [6,7]. These approaches are often cumbersome, as site managers and inspectors manually collect and record progress of construction site activities, and then re-enter the collected records and interpret them at the site office [8]. Moreover, this process is extremely slow as it takes approximately 20–30% of the feeders' daily efforts to update the construction activities [9,10]. This manual-based site monitoring and updating system has several limitations, such as missing, incomplete or incorrect information. Consequently, Project Managers (PM) commonly fail to obtain reliable progress details. This approach tends to lead to confusion, often leading PMs to misjudge the actual progress in their projects. Subsequently, unsound decisions are made, which has severe consequences on the effectiveness of the use of resources. For example, Kim et al. [8] reported that, based on the manual progress monitoring system, a PM judged an activity to be only 30% finished, while in reality, it was 60% completed. In this case, the PM believed that the construction project was delayed, even though it was proceeding ahead of the planned schedule. Consequently, the PM deployed more resources than needed to that activity, which resulted in a

* Corresponding author.
E-mail addresses: Hany2.Omar@live.uwe.ac.uk (H. Omar), Lamine.Mahdjoubi@uwe.ac.uk (L. Mahdjoubi), e.gamalkheder@gmail.com (G. Kheder).

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waste of time and money. This demonstrates that current monitoring systems are often unreliable, time-consuming, costly, and prone to subjectivity and errors [11,12].

To address construction projects' overrun, rigorous and reliable monitoring systems are needed to detect rapidly delays together with their root causes in order to alleviate them, once occurred [13]. Over the last few decades, a great deal of work sought to improve conventional monitoring, updating and controlling systems in the construction industry [14,15]. In the same context, early efforts applied standalone technology to monitor and control construction site activities, but due to their inherent limitations, recent research sought to combine two or more technologies to improve the results of their monitoring systems.

2. Current and emerging site monitoring and controlling systems

Several attempts were made to resolve the salient challenges associated with the limitations of current monitoring and controlling systems. Consequently, a great deal of work has been devoted to develop monitoring technologies. Broadly speaking, these developments could be classified as standalone and integrated technologies.

2.1. Standalone technology

In this standalone proposed system only one technology is utilised [16]. Earlier efforts by Navon [16] focused on the development of a robotic system that could not only install tiles, but also monitor the site as it is equipped with cameras to measure the progress of the installed tiles. However, the robotic system required continuous human intervention for stabilisation and system calibration. Moreover, the robot was monochromatic, which in poor lighting conditions, especially indoors, affected adversely the accuracy of progress measurements. Therefore, the proposed robotic system lacked accuracy and reliability. It is worth mentioning that Navon [16] himself considered the system incomplete and required further developments to minimise or eliminate human intervention.

A more developed automatic system proposed by Dick et al. [17], produced an automatic framework acquisition for the 3D as-built model. The model was constructed from a small number of site photos by developing an algorithm that enabled recognition of the structural objects from the site photos. This framework succeeded to a limited extent to compare the as-built 3D model against the as-planned one. However, the results lacked the sufficient accuracy for site monitoring, as the optimum accuracy was 83% for vertical elements and 91% for horizontals.

A further advanced system proposed by Lukins and Trucco [18] used Computer Vision (CV) to develop a classifier that can observe and detect changes (the progress status) during construction through a fixed camera. This was achieved by developing the prior building model and aligning it with the camera scenes to identify the progress. However, the system suffered from several limitations, including weather interference, occlusions, and daylight fluctuations. In addition, the whole system required continuous manual intervention. Consequently, the accuracy of the classifier is subject to the operator's accuracy and as a result makes the system prone to errors and time-consuming.

Software developers such as Autodesk tried to overcome the recognised limitations pertaining to conventional monitoring systems. Autodesk produced enabled a semi-automatic cloud based system to collect data from construction sites using Personal Digital Assistants (PDA) such as tablets or smartphones. Generally, PDAs overcame some of the recognised limitations, especially those related to the time required to collect data [8,6]. However, the Autodesk's developed software/system still relied heavily on the inspectors to manually insert the construction site updates, which were not only subjective but also unreliable. Consequently, this method lacked the instant detection of delays, reliability and accuracy.

A more promising system proposed by Bosché [19], sought to automate progress monitoring in construction sites by developing a point matching method using the Iterative Closest Point (ICP) recognition algorithm. This was achieved by using Laser Scanning (LS) technology to build a 3D point cloud model, which was then compared with the as-planned Building Information Model (BIM).

BIM involves the development and use of "a computer software model to simulate the construction and operation of a facility. The resulting model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data are appropriated and analysed to generate information that can be used to make decisions and improve the process of delivering the facility" [38]. Eastman et al. [20] claimed that, using the BIM produced error-free design and boosted offsite prefabrication.

Bosché [19] succeeded in achieving optimal registration and comparison between the project's Computer-Aided Design (CAD) model and the site LS model. The ICP approach was applied for comparison-based registration to estimate the differences between the two models. This system seemed promising but it relied heavily on manual interventions to perform synchronisation between the two models (i.e. as-built point cloud and as-planned models). Overall, this system is prone to human errors due to manual interventions, and is therefore time-consuming. Bosché [19] himself considered the system as quasi automated. Above all, LS technology is not suitable for the majority of construction sites, due to its high costs, as well as the expertise needed for operation.

2.2. Integrated technologies

It is clear that standalone systems that use single technology are confronted with several limitations. Consequently, there has been a quest to integrate two or more technologies to combine their benefits, and to reduce the adverse effects of the standalone technology [21–23,9,24,25,5].

The thrust of recent efforts shifted attention to mixed technologies to address the limitations of stand-alone technology. Accordingly, El-Omari and Moselhi [21] proposed the integration between LS and photogrammetry to enhance the speed and accuracy of the acquired data from construction sites. The system succeeded in building a 3D as-built point cloud model with satisfactory accuracy by integrating LS and photogrammetry techniques, by synchronising the common points between the two point cloud models. Using the constructed 3D point cloud model, a comparison could be performed between the progress (as-built) model and the as-planned model. One of the main limitations of this system is the long time needed to perform a single scan. Indeed, to scan the entire built asset multiple moves are required from different positions, which make this system time-consuming and cumbersome. In addition, specialised technicians are often needed to perform the scans to collect accurate data. Above all, LS technique is still relatively expensive, which hampers its applicability for regular updates of construction site activities or to support timely and informed management decisions.

A similar system proposed by Ibrahim et al. [22] relied on CV techniques to develop a progress monitoring system. This system analysed the geometric and material properties of the components in a BIM model and compared it with the corresponding elements from the collected site photos (the as-built). The comparison helped to identify the changes, reflected in the progress status of