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Integrating geometric models, site images and GIS based on Google Earth and Keyhole Markup Language

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ABSTRACT

Technologies for information management and visualization are instrumental in enhancing human perceptions and interpretations of complicated project information. 3D/4D modeling, Virtual Reality (VR), Building Information Models (BIM) and Geographical Information Systems (GIS) have been increasingly used for data management and analytics in construction. Apart from virtual models, it is essential to represent the ever-changing site reality by integrating images captured with drones, mobile devices, and digital cameras. To improve the cognitive perception of the site environment from fragmented datasets, this paper proposes a framework to integrate unordered images, geometric models and surrounding environment in Google Earth using Keyhole Markup Language (KML). A ground-control-free methodology to geo-reference sequential aerial imageries and ground imageries is proposed in order to place unordered images into the physical coordinate system of Google Earth. To combine geometric models, site images and panoramic images with the site surrounding environment in 3D GIS, a KML and cloud storage based data management system is conceptualized to handle large scale datasets. The research provides construction engineers with a low-cost and low-technology-barrier solution to represent a dynamic construction site through information management, integration and visualization.

1. Introduction

A successful project control system requires not only a practical plan to carry out, but also a feedback loop to check the current status of the site, evaluate the performance of field crews and adjust the plan based on updated circumstances. As such, with heterogeneous sources of as-planned and as-built information integrated and well-presented, a transparent construction site information system will be instrumental in problem identification, formulation and further analysis. It also provides the basis for a *SmartSite* [1] enabling timely optimized decision making during design, planning and construction stages. As an fragmented industry involving numerous stakeholders and specialist trades [2,3], data, documents and digital files which are obtained during the project life cycle to keep track of both design and actual construction processes– are also highly scattered, diversified and unstructured. The use of various data sources and formats makes information generated during the course of construction even more fragmented [4]. It raises potential difficulties in making a genuine decision which requires a complete assessment of all the information buried in each piece of data [5–7]. Often, failure to effectively manage and retrieve information may result in delays, missed opportunities or poor decisions [8]. Extra cost upon data collection and storage is incurred and extra time on information retrieving is spent. If such huge amounts of data are not managed efficiently and interpreted in a timely and integral fashion, the available data would present construction managers with more of “noise” than “signal”, more of “waste” than “value”.

With the ultimate goal to build an integrated site information management and visualization system for construction field applications, the present research proposes a methodology to seamlessly link data collection, processing, information management and visualization while also integrating as-planned information (represented by geometric models), as-built information (captured by images), and the site environment provided by GIS systems. This enables construction practitioners to have a fast-adaptive, comprehensive visualization and in-depth perception of the dynamic construction site environment with more complete information. In particular, a UAV-centric image collection and processing method is formalized to align both sequential aerial images and unordered ground images into the physical coordinate system with a ground control free approach. Equipped with better localization units, UAV takes aerial images with localization accuracy much higher than ground imageries, which are usually taken by mobile devices and suffer from low quality localization units subject to multi-

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path effect of GPS signals caused by surrounding environments. By taking the optimized geo-locations of aerial images as references, ground imageries are aligned in the physical coordinate system precisely in an automated manner. Additionally, a KML based construction site information management and visualization system is prototyped. The research investigated the capability of KML for handling unstructured data typically collected on construction site, especially unordered images and as-planned models. By selecting the Google Earth as the platform technology, this research also demonstrates the possibility of integrating images, geometric models, 3D GIS system, virtual reality and augmented reality in a seamless, straightforward fashion while still keeping the application cost low and making construction practitioners the eventual beneficiaries of the research deliverable.

The paper is organized as follows: First, we investigate various types of information and data commonly available on a construction site. Then we review state-of-the-art technologies for integrating and managing heterogeneous information. Next, we introduce the general framework of the proposed methodology, along with two major components: UAV-centric image alignment and processing, and KML based image and 3D model management system, which are explained in detail in the following sections. After that, two case studies are presented to illustrate applications of the proposed methodology for pre-project planning and project control. At last, we summarize the advantages, contributions and limitations of the proposed methodology in terms of technological originality and industry impact.

2. Literature review

In the past decades, data sources to support construction decision making have been significantly enriched due to the adoption of geographic information system (GIS), Building Information Models (BIM), various location sensors and material tracking devices, and ubiquitous images captured from mobile devices and unmanned aerial vehicle (UAV) systems [9–11]. As-planned models with rich geometric information have shown great potential in congestions analysis on construction site [12], temporary work and access planning [13], safety monitoring [14], environmental impact visualization [15], site layout planning [16,17], crane path and lift planning [18], and other construction site activities [13,19]. Considerable effort has also been put on the automation of progress monitoring [10,20,21] based on comparison between the as-planned model with 3D reconstruction for the site from unordered site images [22,23] and laser scanning [24–26]. Apart from original photos, most recent research focusing on adapting the panoramic image stitching algorithm also emphasized the importance of panoramic view upon site management [27]. However the adoption is greatly hindered by (1) high expenses on system development but unclear benefits of implementation [5,28,29], (2) inefficient visualization and oversimplified site modeling compared to complicated site environment [29], (3) insufficient integration and interoperability [30,31], and (4) technology barriers and organizational difficulties in information sharing and distribution [29,32]. Recent works [33] recognized challenges and limitations of current analytical approaches, including lack of spatiotemporal functionalities and capacity, absence of site logistics, accessibility and route planning, inefficient visualization, and lack of human involvement and interaction. Other works [29,34] increasingly emphasized the critical role of visualization, information integration and user involvement upon final plan validation and modification in site layout planning.

However information visualization presents a distinctive challenge in general due to diversified usability requirements from different users, scalability to handle large scale of datasets, difficulty in integrated analysis of heterogeneous data from varying sources, in-situ visualization ability requiring timely and incremental updates, and errors and uncertainties in the data [35]. As a fragmented industry, these challenges become more severe in construction. Augmented reality (AR) [36,37] gained substantial attention recently due to its capability to combine as-planned information and as-built information. Despite operational level applications, AR was used in most recent work [38] for electrical design communication during design and planning stage. The D^4AR system [39] was capable to visualize project wide progress by highlighting the discrepancy between the as-planned model and the images captured with video cameras mounted on several stations surrounding the site using AR technology, thus enabling intuitive progress visualization. Nonetheless, the capacity for information integration and exploration is still limited due to fixed camera positions, unknown absolute scales. Most importantly, the absence of an accurate model of the surrounding environment, for example 3D site models provided by 3D GIS systems, makes it less instrumental for applications entailing frequent, intensive interactions between the facilities being built and the site environment, especially where the project is situated in crowded or environmentally fragile areas. Additionally, visualizing large volumes of images might also be challenging for D^4AR without a comprehensive "level of detail" (LOD) system. Researchers also leveraged on the benefits of integrating BIM and AR [34,40–42]. However incorporating AR into BIM software is still practically infeasible due to inherent limits of BIM software handling large datasets and real-time rendering [34].

To tackle unstructured data, much related research has focused on the utilization of standardized extended markup language (XML) as shared project information models due to its extensibility and interoperability on the web schemas [4,43,44]. Both the open source BIM standard Industrial Foundation Class(IFC) [45–47], and Web GIS formats including LandXML [7,47], CityGML [48–51] and KML are based on XML. A combination of BIM providing detailed information of the structure and GIS with rich geospatial information surrounding the construction site also emerged as a very important research area. Some methods tried to map the IFC schema to CityGML schema using ontology based methods and instance mapping [51–53], others attempted to separate geometric information from properties information [53]. These researches demonstrated high flexibility of XML in handling diversified data with varying structures and formats.

3. Methodology

As the most popular virtual globe platforms, Google Earth is not only widely used by public users, but also scientists, and stakeholders in addressing environmental and construction planning issues because of its rich geographic information. Diversified geographical information is presented to the user through a combined visualization of digital elevation models, satellite imagery, 3D building models, street views and user uploaded images. Tiling and LOD for images and 3D models enable Google Earth to manage large datasets which is challenging for BIM software. However its ability to integrate fragmented data of a construction site taking a location based data management approach is far from explored. Besides, KML enriches the extensibility of the software significantly by providing users a standardized language to add customized data. The Google Earth system serves as a cost effective and low technology barrier information exploration platform, as well as an information management system. With temporal and spatial information associated with each object, the system enables efficient information retrieval through contents navigation, 3D exploration and time window filtering.

What underlies the integrated construction site information management system is a KML based methodology that integrates information contained in unordered images, geometric models and 3D GIS system. As presented in Fig. 1, the system covers data collection, data processing, data management and information visualization and distribution. Efficient construction site data collection is critical for project planning and control which demands timely reaction. Therefore aerial and ground imageries of the construction site captured with UAV and mobile devices are selected as the major data sources for actual site monitoring. Apart from that, as-planned models and schedules are