An Interactive Progress Monitoring System using Image Processing in Mobile Computing Environment

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Abstract -

A timely progress monitoring is essential for the success of a large-scale construction project. It enables a site manager to properly prepare resources and make plans for the remaining part of the construction activities. Recently, mobile computing and image processing have been investigated as a means of automating progress monitoring. Mobile computing is advantageous in wireless data recording, retrieval, and transfer whereas image processing is able to analyze the site images to extract progress information. However, their potential applications in construction monitoring were rather separately studied; synergistic effect of both techniques has not yet been fully materialized. This paper presents an interactive mobile progress monitoring system to enhance the existing progress monitoring practices. The system utilizes the interactive feature of tablet computer to combine the strength of image processing and mobile computing. When a user selects an object on a construction site image in a mobile computing environment, the system provides a list of attributes for the object of interest. In this interactive environment, the user can easily match the object to the right attributes such as location, material type, and relation with other objects. This initial matching can then allow for automatic matching of other objects on the site to the right attributes of their own. The method can raise accuracy of image processing and significantly reduce the effort required to do the pre-processing for progress monitoring. A cable-stayed bridge construction project, a case study, is used to validate the proposed system.

Keywords -

Construction management, Progress monitoring, Image Processing, Mobile Computing, Cable-stayed bridge

1 Introduction

In a large scale construction project, multiple activities are simultaneously conducted; a well-coordinated effort is needed to timely prepare the necessary resources, such as labor, equipment, and materials, for uninterrupted smooth execution of the project. However, changeable and uncertain site conditions often necessitate change of the original design or plan. The change management requires efficient communication among the participants of the project. One of the important subjects for communication is the progress status. Delay in the transfer of the progress information prevents project managers from making optimal management decisions, resulting in increase of the project cost. Thus, implementation of an effective communication system to monitor and share progress information is crucial for project success.

Mobile computing technology is emerging as a viable solution to handle the construction site information. Radio frequency identification (RFID), ZigBee, and smartphone technologies are being studied for improved site monitoring processes. To name a few examples, Kim et al. (2011) used RFID and ZigBee technologies to implement the ubiquitous sensor network for construction material monitoring [1]. Chen and Kamara (2011) proposed an information management framework to use mobile devices for acquiring and transferring site information [2]. Kim et al. (2013a) proposed using smartphone technologies for site monitoring, task management, and real-time information sharing [3].

Image processing is being investigated as a way to automatically capture and analyze construction site information. Wu et al. (2010) developed the 3D CAD-based filtering method to increase the accuracy of object identification in construction site images [4]. Chi and Caldas (2012) proposed image processing to monitor the safety status of earth moving operations [5]. Kim et al. (2013b) automated the process of 4D CAD model updating using image processing [6]. Rebolj et al. (2008) conducted construction activity monitoring using 4D model and image processing and shared the resultant information with site personnel using mobile devices [7].

Kim et al. (2013) proposed an automatic registration method to link 3D data from Lidar and 3D CAD model for progress monitoring [8]. Golparvar-Fard et al. (2009) presented a visualization technique to overlay 4D Simulation model on time-lapsed photographs for identifying as-planned and as-built progress discrepancies [9]. Golparvar-Fard et al. (2012) developed an automated progress monitoring method using unordered daily construction photographs to update and identify the progress of IFC-Based building information model [10]. M. Ahmed et al. (2012) presented a progress monitoring method for complex pipe-works using a digital camera [11]. Y.M. Ibrahim et al. (2009) utilized an image processing technique to automatically interpret the progress state of site images. Your manuscript must be submitted to our online peer-review management system [12].

Synergistic effect can be expected by using both mobile computing and image processing technologies for improved construction management. However, there is a lack of effort in combining the two technologies, and the opportunity has not yet been sufficiently gripped. This paper presents an interactive progress monitoring system based on image processing and mobile computing. Capitalizing on the strength of the two technologies, the progress information can be retrieved on site with high accuracy and the information can easily be shared with the project participants. One of the main contributions of this research is the flexibility of image processing techniques for progress monitoring. In the previous efforts in this area, users of progress monitoring techniques had to customize their algorithms to the site and naturally involved a lot of laborious tasks. The proposed system can be utilized as a tool for minimizing such efforts. The system requires the minimum intervention of users to automatically identify the whole progresses. The system was validated using a case study involving construction of a cable-stayed bridge.

1.1   Case Study Description

The proposed progress monitoring system was applied to the upper deck installation activities of the cable-stayed bridge construction. The bridge, located in Jecheon, Choongcheongbuk-do, Korea, has a length of 442m and a width of 14.5m, with two pylons. A total of 28 segments of upper decks comprise the superstructure of the bridge. Each deck was installed in the order of edge girders, floor beams, stringers, concrete panels, and in-situ concreting. The process of component installation, from edge girder to concrete panel, was supported by a derrick crane, and the whole process, even including in-situ concreting, was repeated for each

deck installation.

In order to capture the images for deck construction, a closed-circuit television (CCTV) camera was installed at the cross beam of a pylon. The camera had the resolution of 704×480 and was equipped with pan, tilt, and zoom (PTZ) capabilities. The construction scenes were captured at a rate of one picture per second and the saved images were transferred to the main server in the form of JPEG.

2   An Interactive Progress Monitoring System

Figure 1 shows that the interactive progress monitoring system is composed of two hardware units: mobile device and main server. Mobile device is to interact with users for information input and output, whereas the main server is to process images and offer the site information. Since image processing in mobile computing environment requires high-level computing power, the server was used for the image processing part. The mobile device was used as the interface through which users interact with the system. In this system, MATLAB, Hypertext Preprocessor (PHP), and Microsoft Windows Server were used. PHP language was favored because it could generate a mobile website that could be accessed by any mobile device, irrespective of the operating system. The mobile website developed for the system, thus, could be accessed by Android users and Apple iOS users.
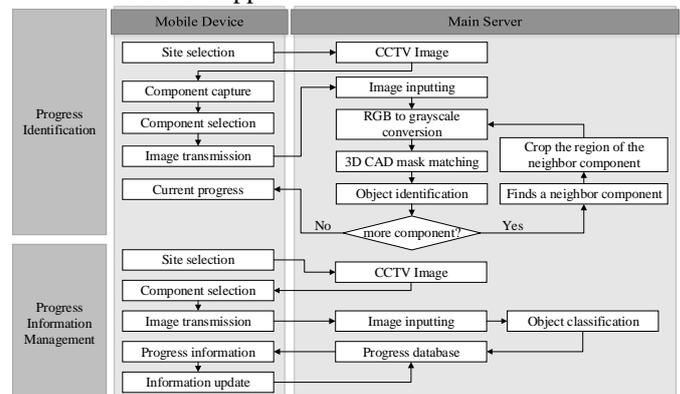

Figure 1. Interactive progress monitoring in mobile computing environment

To increase the level of automation of the system, the MATLAB source files were converted to executable files. Once the executable files were developed, they were, as the name indicates, executable by the commands transmitted through the mobile website. For the generation of the executable files, the MATLAB compiler toolbox was utilized. The compiler toolbox

was to build executable files from MATLAB source codes, with the help of additional program compiler; in this study, Microsoft Visual Studio 2010 was used. The executable files generated in this way could be run in a computer system where MATLAB Compiler Runtime (MCR) was installed. As a result, the image processing functions could be performed seamlessly based on the commands from the mobile website.

From the functional perspective, the proposed system consists of two parts: progress identification and progress information management. The progress identification is to extract the current status of the project using the image processing, while progress information management is to retrieve progress information concerning the component of interest and update the database based on new information.

The progress identification part plays the role of raising accuracy of object identification in the image processing, and thus reduces the effort required to do the preprocessing for progress monitoring. First, a user selects the construction scene of interest, and then the image of the scene such as the one shown in Fig. 2 is sent to the mobile device. Next, the user can choose the component of interest by using the box like the one shown in Fig. 3(a). The image inside of the box is cropped and later used for pattern matching with a 3D CAD mask. The user can also choose the identity of the component using a list such as the one shown in Fig. 3(b). Both information (image and identity) are now sent to the server. The server now starts the image processing shown in Fig. 1 by relying on the information (image and identity).


Figure 2. CCTV image of the cable-stayed bridge

For the image processing, the cropped RGB color image is first converted to a grayscale image. The grayscale image is now, with the help of the identity information, associated with the 3D CAD mask. Here, the 3D CAD mask is the image obtained in the CAD environment assuming the same angle, magnification,

and perspective origin of the CCTV as shown in Fig. 4. The mask can be used for effective identification of construction components [4]. The 3D CAD mask (Fig. 4) is compared with the cropped image using the normalized cross correlation, to check the existence of the component. Once the whole process is completed, using the relative locations among the components of the segment, the same process is repeated for the other components until all components are checked. In this way, the progress identification can be done in the automatic manner and the current progress information is displayed to the user.
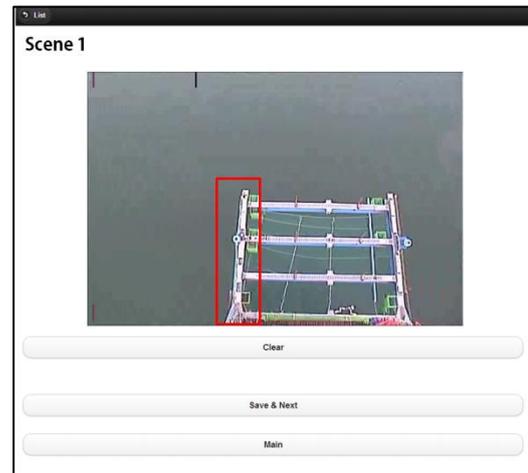
(a) Component capture
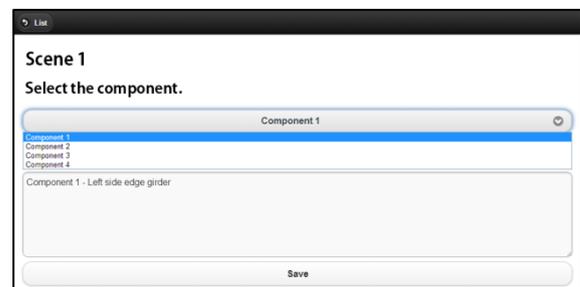
(b) Component selection

Figure 3. Mobile progress monitoring web site interface

The progress information management part allows the user to retrieve progress information from the database; any input acquired from the mobile device can be used to update the database. For this function, the user first needs to select the site of interest in order to receive the corresponding site image. The user now can choose a particular component to extract its related information including the supplier, date of installation, and installation contractor. The user can also update the database with new information, such as most recent site pictures and comments of site inspectors. As for now,

the progress information management part is not yet fully implemented as a part of the system.
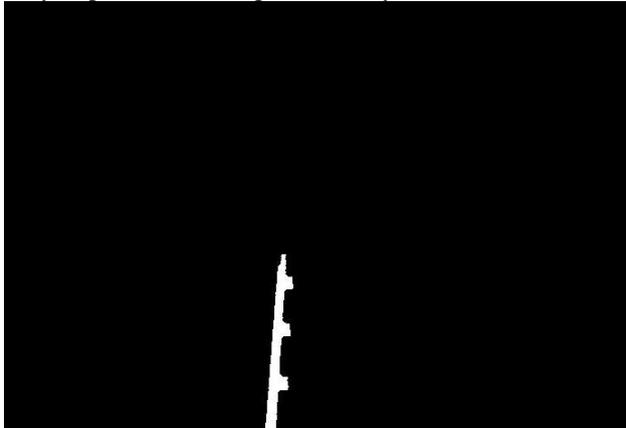

Figure 4. 3D CAD mask filter of the selected component

3   Conclusions

This paper proposed an interactive system to effectively monitor progress of construction sites based on mobile computing and image processing. Mobile device was used as the interactive interface platform by which the user can extract progress information from and input project information into the system. Image processing was used to automatically calculate the current progress level of the project. Combined together, the two technologies increased the level of automation of construction progress monitoring and image processing accuracy. Additionally, omnipresence of site information through the mobile device allowed the users to have prompt decision making process.

Future studies are still required. As previously mentioned, the progress information management part needs to be fully implemented. In addition, the system needs to be improved so as to be able to extract progress information from the images captured directly from the mobile device. Such improvements are expected to make the system readily applicable in real construction projects for significant increase of construction productivity and quality.

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