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TRACKING CONSTRUCTION PROJECTS PROGRESS USING MOBILE HAND-HELD DEVICES

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Abstract: Recent studies have attempted to automate monitoring progress of construction projects using 3D laser scanning or image based reconstruction methods. This paper presents a new methodology for monitoring using mobile hand-held devices such as smartphones and tablet computers. This is done by proposing a new developed android application called "BIM track" that the end-user can use to record the progress of activities (actual dates, percentage complete, and actual cost) from a remote location. BIM track is cloud-based which ads in speeding up the production of construction progress reports and improves data accuracy as it's connected with Google drive using fusion tables that make the user able to combine/edit the data on the internet. As such, it is capable to collaborate, visualize, and share data through the internet to export the results into an Excel spreadsheet from the mobile application to a remote computer. In addition, the data can be imported to the Navisworks to update the project's 5D model. Accordingly, time schedules, cost performance (CPI) and schedule performance index (SPI) can be calculated easily. In addition, such results can be shown in 5D model using Navisworks to compare actual progress versus the planned progress. BIM track android application can have an access to any uploaded project's 3D model using Autodesk 360 as this application is integrated with BIM track. A case study is presented below to demonstrate the use of the proposed methods to track the project and to make a comparison between the actual and the planned progress of the project.

1 INTRODUCTION

Nowadays, there is major developments in Mobile hand-held devices technologies that are highly prevailing that is no longer limited to personal use. Portability and accessibility granted the Mobile hand-held devices such as smartphones and computer tablets a great advantage that attempt recent studies to automate the process of construction site monitoring. A recent survey conducted by McGraw Hill reveals that 93% of random samples of general contractors and subcontractors are now using mobile devices on their jobsites to document workflows (Bernstein and Russo 2012). There are several aspects for improvement in productivity of onsite operations. Any onsite information management system should have the following characteristics (Bowden, et al. 2006) (Golparvar-Fard, et al. 2011) (Son, et al. 2012) (Bae, Golparvar-Fard and White 2013): 1) enable project monitoring capabilities 2) provide easy access to relevant information so that onsite resources could be managed more effectively, and 3) function in near real-time to share information and facilitate interactions among project participant. (Kim, et al. 2013) listed five different categories of studies for mobile computing of construction: 1) development of a framework or platform to demonstrate how mobile computing should be used for construction; 2) mobile computing as a toll for identification or general management; 3) mobile computing for defect management; 4) mobile computing for safety or disaster management; and 5) development of specific features of mobile computing.

As a step towards improving the productivity on site, it is required to perform beneficial reporting system to provide the opportunity for project management to detect the performance deviations. However, typical practice for progress tracking mostly depends on supervisors daily or weekly reports, which involve intensive manual data collection and entail frequent transcription or data entry errors. Field engineers and/or superintendents along with 2D as-planned drawings, project specifications and construction details to review the progress achieved by that date then study these reports. After that, they study the construction schedule to identify the work planned to be done by that date. This requires a significant amount of manual work that may affect the quality of the progress estimations (Kiziltas and Akinci 2005).

To overcome such limitations, recent researches trend moves towards improving construction monitoring through model-based assessment methods, where the expected performance is typically modeled with 4D Building Information Models (BIMs) and actual performance is sensed through 3D laser scanners (Turkan, et al. 2012) (Kim, et al. 2013) or a 3D sensing techniques called 3D image based reconstruction methods (Golparvar-Fard et al. 2009, Golparvar-Fard et al. 2011, Golparvar-Fard et al. 2012). In this paper, the proposed methodology makes benefit of the advantages of the mobile hand-held devices to develop an android application to monitor the construction projects through cloud based service. Time schedule is loaded along with the cost for each activity to generate a 5D model to calculate the planned, and actual values cost during the project. A case study is presented in which this application is deployed on a construction project to endorse its capability to track projects to compare the results.

2 DEVELOPMENT OF BIM-TRACK APPLICATION

This research aims at optimizing the built-in advents of smart phones with other technologies to provide an effective monitoring for progress on-site. (Kim, et al. 2013) listed the advents of smart phones that have become the standard of most smart phones can be classified into Global Positioning System, High-resolution color touch screen, sensors, camera, and high-speed data transfer. BIM-Track android application acquire from the aforementioned advents the High-resolution color touch screen to allow the user to read/add information through the high-speed data transfer to upload captured images integrated with its location as shown in the sections hereunder.

2.1 BIM-Track Structure

In the last few years, the trend toward the mobile computing has significantly increased in the construction management field. BIM-Track mobile application is developed using a combination of the following:

1) Primavera P6 R8.3 (Oracle 2015): P6 Professional is a comprehensive, multi project planning and control software, built on Oracle and Microsoft SQL Server relational databases for enterprise-wide project. Primavera is used to issue a time schedule using CPM (Critical Path Method) and to assign the activities cost for further cost control reports.
2) Revit 2014 (Autodesk, Revit 2015): Revit software is specifically built for Building Information Modeling (BIM), empowering design and construction professionals to bring ideas from concept to construction with a coordinated and consistent model-based approach. BIM Track used this program to create a 3D model.
3) Navisworks 2014 (Autodesk, Navisworks 2015): it is an application which allow the users to integrate the created 3D model with the time schedule and its assigned cost to produce a video that shows the 5D simulation in the project in various stages.
4) Autodesk 360 (Autodesk, Autodesk 360 2015): Autodesk 360 is service provided by Autodesk that allow to share and organize all project data, collaborate on 2D/3D model on the web or on the smart phone.
5) Fusion tables (Google 2015): It is an application similar to Microsoft Excel connected with Google drive that is able to combine the data on the web, collaborate, visualize and share. This service are used in this paper for updating the activities actual durations, actual start, actual finish, performance, and actual cost, etc. where these results can be filtered and summarized across hundreds of thousands of rows.
6) Matlab (Image Processing toolbox) (Mathworks, Image processing tool box 2015): provides a comprehensive set of reference-standard algorithms, functions, and apps for image processing, analysis, visualization, and algorithm development. Image analysis can be performed employing different

techniques including, image segmentation, image enhancement, noise reduction, geometric transformations, and image registration. This tool is used to analyze the progress of the captured images 7) MIT App Inventor (MIT app inventor 2015) App Inventor is a cloud-based tool that can build android apps using web browser through Java programming language. This tool is divided into a group of blocks that have functions and a design interface for application designing to ease the use with the end-user.

Figure 1 illustrates the supportive applications that constitute BIM-Track" Application.

Figure 1: Supportive Applications for BIM-Track

2.2 BIM-Track Data Flow

Tracking projects process, in a form of acquiring information and capturing images, is performed by visiting the field office and construction sites. The proposed BIM-Track application provides improved accessibility of project information and site images. Before updating the project's information, the end-user of the proposed application can obtain the basic information of the preloaded projects that is prepared in the head office. Moreover, the integrated Building Information Model to the application can save time and help in taking fast decision on site, where these benefits are based upon the level of detail of the model. The level of detail (LOD) can be categorized through system published by AIA. (Bedrick 2008) defined five categories for Level of Details (LOD); the LOD 100 as a conceptual stage, LOD 200 as an approximate geometry stage, LOD 300 as a precise geometry stage, LOD 400 is fabrication stage, and LOD 500 as as-built stage.

However, the project information needs to be updated to track the project's status, this happens through the accessible devices as shown in Figure 2. First, the 2D/3D drawings provided by Autodesk 360 have an access to add any comments on the selected element to allow for interactive drawing sharing among the application users to provide the required information and this happens through Mobile computing system. Moreover, the captured image that is assigned to a specific element in the 2D/3D drawings can be used to track the performance in the project. RGB images are converted to binary images to calculate the actual performance using image segmentation. Second, data provided from the fusion tables can be used to update the Time Schedule and the actual cost of each activity to generate an actual 5D model to be able to compare the actual/planned progress to see the difference between the Actual Cost of Work Performed (ACWP) and Budgeted Cost of work Scheduled (BCWS) through a 5D model.

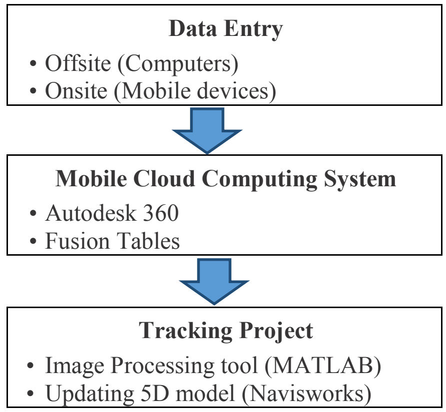


Figure 2: Data flow in BIM-Track

2.3 BIM-Track Interface

Effective tracking of site activities requires a friendly interface for the end-user to ease the usage of the developed android application. BIM-Track start screen shows the options available to the end-users. First, a button that open a preloaded 5D model is uploaded over the internet, which is updated periodically. The 5D model visualizes the difference between the planned and the actuals on the project as detailed in the sections hereunder, where this 5D model is updated after checking username and password of the user. BIM-Track has a button that shows the essential information such as the location, description, stakeholders, perspectives, and estimated cost of the project In the proposed BIM-Track application, two tracking methods are used; fusion tables and the 3D model to capture the images for a specific location or leave a comment to the users (see Figure 3).

Figure 3: BIM-Track Screens

3 SITE MONITORING USING BIM-TRACK

3.1 Image Analysis for Progress Monitoring

Effective tracking for construction projects can have positive results in managing the projects. The developed BIM-Track application enables the users to: 1) visualize the project in 3D, and 2) open the construction project's drawings to minimize time of acquiring hardcopy drawings. Autodesk 360 is used in viewing the drawings for different projects. For each project, it can be loaded with the 2D/3D drawings or both as per the exported .DWFX file extension using Revit 2014. However, Autodesk 360 is not only used for viewing the drawings or visualizing a 3D model, but it is used for tracking projects as well. Figure 4 depicts that progress can be added in comments where these comments can be added to a specific element in the drawings. Such elements can have markups as pin icon on the drawing, area highlighted, and freehand. Moreover, these comments are used to describe the state of work to perform an effective tracking for construction projects. Subsequently, these captured images are imported to MATLAB image processing toolbox to track the progress of works.

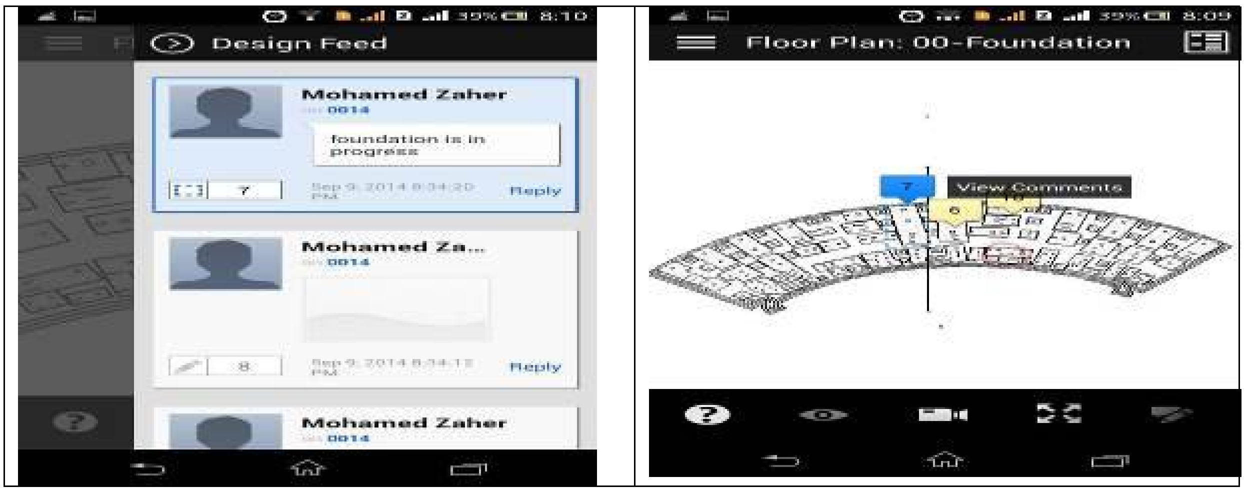


Figure 4: Tracking project using Autodesk 360

Images acquisition of construction sites is a preliminary step, where such images are attached to specific element in the 3D model. However, the image quality must be fine enough to recognize the objects in the image. Autodesk 360 transfers the captured image through the cloud mobile system effectively to be available through any accessed device. Once the captured site image is downloaded to the PC, it can be processed for progress monitoring. Figure 5 illustrates the procedure of image analysis to identify construction progress for executed typical floors in an administrative building. The RGB captured image using the smart phone shows both de-shuttered slab and other shuttered elements. The image processing tool using the MATLAB is capable to identify number of slabs in the image as a horizontal shapes after reducing the noises in the captured image, where, many of steel scaffolds as an example affect identifying the progress in any captured image. To achieve better results with respect to identification of number of performed slabs any noise should be removed or any element but the slab in the image.

Zou and Kim (2007) used HSV color space as the hue is less sensitive to different lighting conditions than RGB images to differentiate between objects with different colors. They stated that in HSV image, objects of different colors tends to be differentiated from another because hue represents the dominant wavelength of the color. However, the considered captured image colors have near RGB values especially for the shuttered slab. Thus, image segmentation takes place through converting the captured RGB image to grayscale image then to a binary image. Separation the grayscale image occurs to have three different planes 1) red, 2) green, and 3) blue. This process is called image segmentation, which is followed by adding this planes to one plane after adjusting the level of each plane to reduce the noise in the binary image to be complemented. In the complement of a binary image, zeros become ones and ones become zeros; black and white are reversed. In the complement of an intensity or RGB image, each pixel value is subtracted from the maximum pixel value supported by the class (or 1.0 for double-precision images) and the difference is used as the pixel value in the output image. In the output image, dark areas become lighter and light areas become darker to fill image regions and holes, where these processes named image enhancement. Mathworks (2014) defined image enhancement as the process of adjusting digital images so that the results are more suitable for display or further image analysis.

Image analysis can take place by measuring properties of image regions using a logical operation in the Matlab as the function 'find (X)' that locates all nonzero elements of array X, and returns the linear indices of those elements in vector. If X is a row vector, then f is a row vector; otherwise, f is a column vector w. If X contains no nonzero elements or is an empty array, then f is an empty array. In our study X is the white part that is valued to be '1' to detect the slab region and surround them by boundary boxes for users to count and identify the slabs.

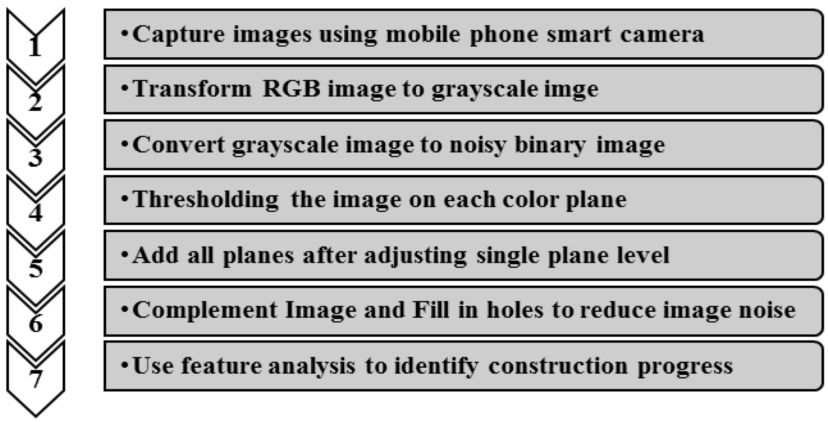


Figure 5: Image analysis procedure.

3.2 5D Model Development

During the execution of any mega construction project, cost control process takes place to track a project to conclude some parameters such as the budgeted cost of work scheduled (BCWS) which is known as the planned value, budgeted cost of work performed (BCWP) which is also known as Earned Value, and Actual cost of work performed (ACWP). BIM-Track application tends to show the difference between the aforementioned parameters through a 5D model and determine if the project is under or over budget and schedule to make the construction managers plan corrective actions (if any), and implement this corrective actions. A case study was conducted through BIM track android application to achieve this goal, where BIM track mobile has the access to add information to update the activities to enrich the tracked project by generating 5D model using Navisworks. First, information that can be acquired in the developed android application varies such as actual start, actual Finish, progress percent complete, WBS code, and the allocation of the activities responsibility to each Engineer on site. Second, BIM-Track transfers the results through google drive, which is a cloud storage service that allows the users to store the updated information using fusion tables. Third, the actual cost of each activity and budgeted total cost can be updated offsite after exporting the updated results from the android application onsite to a Microsoft Excel comma separated value file (.CSV) through the Google drive. Finally, the final results can be synchronized through the previous update which is imported to the Navisworks.

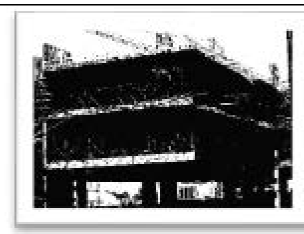
Now that Navisworks contains the time schedule, financial cost, and the 3D model imported. The final task is to attach each activity in the time schedule to the relevant task manually, or using a function called "Timeliner Rules". Timeliner rules can attach the tasks to items with the same name, selection set with same name, and layers with the same name this is according to the generated 3D model technique, where the process of attaching the tasks is one time process as updating the 5D model will depends only on adding the information of each activity.

4 CASE STUDY

As a verification of image analysis for site monitoring, a case study for a construction Mega project for an administrative building located in Smart Village, Giza, Egypt with total area 13,000 m2 was performed to verify the usage of BIM track android application using a Sony Xperia C smartphone with 5 inches TFT capacitive touch screen, 8 Mega pixel front camera with Quad-core 1.2 GHz Cortex-A7 processor. Using mobile 3G/WCDMA networks that enable data transfer. A Joint Photographic Experts Group (JPEG) image format was captured on April 16, 2014 for a typical floor slab to apply image processing to track the project for the concrete skeleton, as the concrete works in the similar projects shall be critical activities. As shown in Figure 6, the converted binary image in figure 6c is noisy and such noise need to be removed, and the slabs shall be clearer. A manual trial and error process takes place for some variables to: 1) choose appropriate level of thresholded color plane to integrate the sum of all planes, 2) the intensity of the filled holes in the converted binary image. For evaluation process, the progress information represented with the user visual recognition compared with the Matlab results after trying different values for the variables to validate the counted number of slabs as illustrated in Figure 6. As a preliminary result, it was found an incorrect progress due to the disruption caused by the horizontal parts of the steel scaffolds and the shuttering, wherefore filled holes value between slabs has been increased to get the result as shown in Figure 6g.

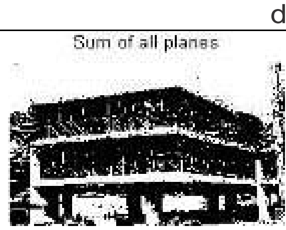
a) Captured image

b) Transformed RGB image



c) Converted grayscale image

d) Thresholding image on each colors' planes



e) Combining All Planes

f) Reducing Image Noise

g) Identified features

Figure 6: Case Study Image analysis procedure.

Moreover, it shall be mentioned that it’s recommended to fix the camera in same position and level to easily identify further progress without any trail and errors for image analysis to keep sure that the whole process is automated. This place recommended to be out of reach to keep sure that the position did not change every update. Tower cranes is highly recommended for this process. Whilst for the verification of generating a 5D model for the same project and scope of concrete works, BIM-Track android application was tested for sharing the updated activities to Google drive fusion tables over the internet, where the input data were activity name, performed progress percentage, actual start, actual finish, WBS code, and the site engineers allocated to the activity. These data were used to update the time schedule on the Primavera with data date May 17, 2014 to update the previous update with data date May 10, 2014. And thereafter, the updated time schedule was exported to the Navisworks in .CSV format to synchronize it with additional data calculated with the Primavera. This data were the planned value, earned value, and the actual cost of work performed for the activities. As such, the Navisworks was able to export three 5D model for May 17, 2014 data date to 1) Monitor project, 2) visualize the updated/planned 3D model where the process of fixing the steel reinforcement is presented in red color, shuttering for columns and slab is presented in yellow color, and at the end of pouring concrete activity is presented in the model final appearance (see figure 7) and 3) Compare the final total cost. These results were used to calculate important parameters for cost control management to check if the project is under or over budget, and ahead of behind schedule using the following functions, considering Cost Performance Index (CPI), and Schedule Performance Index (SPI), respectively as shown in Figure 7. The results show that the project is under budget, and behind schedule where the estimated CPI and SPI are 1.02 and 0.94, respectively. These results need a proper immediate action to recover within the next updates that is performed on a weekly basis.

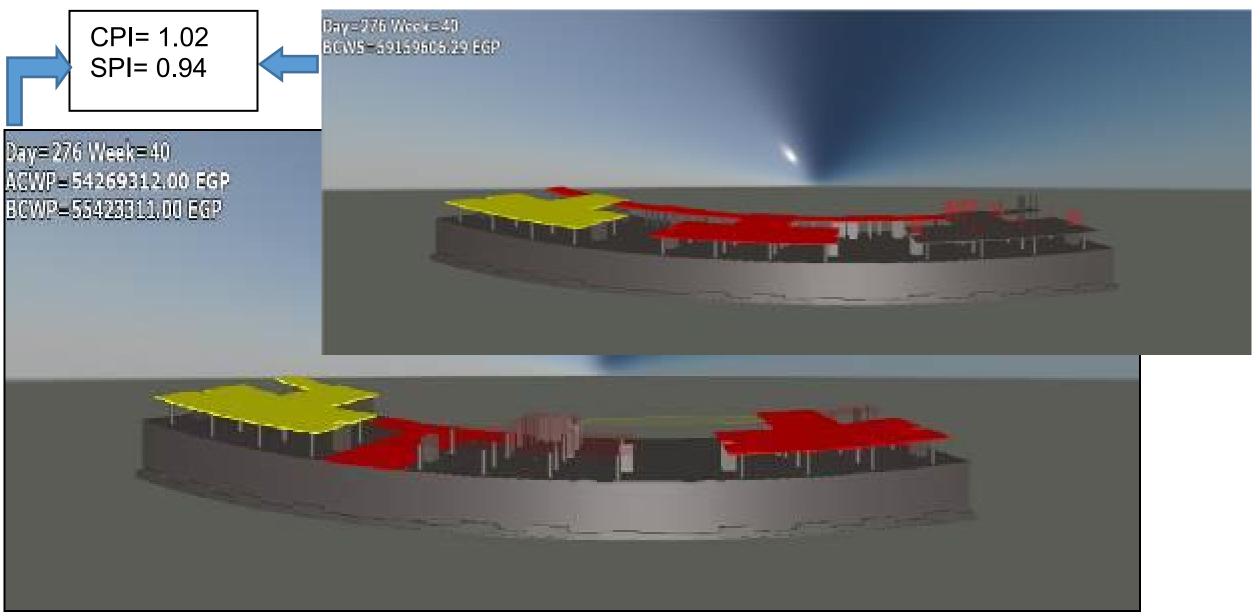


Figure 7: 5D model visualization.

5 CONCLUSIONS

Mobile hand-held devices such as smart phones, and tablet computer with other computing technologies provided a powerful system for tracking construction projects. The objective of this study was to develop an android mobile application connected with other applications to aid in tracking projects through storing the updated data over a mobile cloud computing system. BIM-Track the developed application have two method of tracking which are image analysis for progress monitoring, and 5D modeling for the planned and actual progress. The application enables project monitoring and it provides easy access to project’s information, and facilitates the visualization interaction through the 3D model. Image analysis provided information about the captured images using Matlab, whilst Navisworks used the updated information form the fusion tables to generate the 5D models. A case study for Administrative building under construction was presented to illustrate the use of the proposed application.

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