Rapid 3D Modelling of an Existing Building using Photos

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Abstract -

A three-dimensional (3D) laser scanner is one of the most well known devices when it comes to creating a 3D model of existing bridges and buildings. Most 3D scanners can pick up point clouds very accurately, which can be used to create an accurate 3D model of existing objects. One may speculate that a 3D laser scanner can also be used to pick up the status of a construction project on the job site and transform them into a 3D computer model. However, most 3D laser scanners are still expensive and they are not easy use yet especially on a congested construction site. In addition, it takes a significant amount of time to create a 3D computer model using point clouds picked up by the laser scanner. As emerging photogrammetry techniques demonstrated the use of photos instead for rapid 3D modelling, one may be wondering 1) if this technique can be used to create a 3D model of a construction site quickly, and 2) if this model is accurate enough to help project managers make some decisions. This paper presents our test demonstrating the process of creating a 3D model of an existing building using photos. It presents some challenges we faced when taking photos and creating a 3D model. This paper also presents the method we came up with to create a 3D model of the entire building without using any control points.

Keywords -

3D CAD Model; Photogrammetry

1 Photogrammetry

Photogrammetry is a technique of creating a 3D model of an object from one or more photographs of that object. Software tools introduced recently facilitate object reconstruction and creation of a 3D computer model from digital images without requiring the domain knowledge of photogrammetry.

Photogrammetry has been used in many areas including architecture, heritage preservation, engineering, forensics and accident reconstruction, and medical applications. Almagro et al. [1] produced a model of the Otto Wagner Pavilion in Vienna using photos, which is used by CIPA (the International Council on Monuments and Sites) as a reference building for testing modern methods of measurement and processing in architectural photogrammetry. Arias et al. [2] combined the graphic and metric documentation on the traditional agro-industrial buildings, which are an important part of the heritage of Galica (Northwest of Spain) using close-range photogrammetry techniques.

Mills et al. [3] measured deformation of a pavement within the Newcastle University Rolling Load Facility. Precise 3D measurements of the pavement have been produced from stereo-imagery taken with different cameras, using both analytical and digital photogrammetric instrumentation.

Przybilla et al. [4] presented all the stages involved in the procedure for the determination of the shape of a fuel assembly, which is an essential part of a nuclear power plant and can only be handled underwater. Photo-triangulation was used to obtain orientation elements, taking into account light refracting surfaces. Stereo-models were then set up for analytical restitution and the shape parameters for the object can be obtained.

Fraser and Riedel [5] monitored the deformation a series of super-hot steel beams using digital close-range photogrammetry. An on-line configuration of three CCD cameras was established to measure both stable reference points and targets subject to positional displacement.

Fenton and Ziernicki [6] presented a method of determining a vehicle crush and equivalent barrier speed using digital photogrammetry. Close-range photogrammetry allows engineers and accident re-constructionists to create 3D computer models of damaged vehicles utilizing photographs. Utilizing photogrammetric software PhotoModeler, engineers can digitize accident scene photographs and create accurate 3D computer models of the vehicles, which then can be used to quantify structural damage sustained by the vehicles. Knott Laboratory utilized these techniques on a case of Princess Diana accident in France.

Lynnerup and Vedel [7] analyzed surveillance images from a bank robbery, and the images were compared with images of a suspect.

Burke and Beard [8] monitored facial shape as it changed over an extended period of time through growth. Walton [9] involved photogrammetry in the therapy of various gait problems arising primarily from deformities or injuries.

2 Photogrammetry in Construction

Abeid et al. [10] integrated the site construction progress bar chart in MS Project with a database of digital site pictures showing the building process and building elements at particular points of time. The digital pictures taken from up to four cameras are placed on a website, where a remote computer can capture and store the pictures in the database. The system enables management staff of contractors and owners to follow developments at the construction site in real time. Additionally, time-lapse films of activities at the construction site taken by multiple cameras can be played back in synchrony with dynamic graphs showing planned versus actual schedules. A new concept in time-lapse photography has been introduced. It enabled a reasonable playback time as well as the implementation of the technology for long-term construction projects using standard personal computers.

Kim and Kano [11] suggested a method for determination of the 3D viewpoint and the direction vector of a construction photograph to perform comparison of the construction photograph and the corresponding virtual reality (VR) image. They developed photo images in 3D computer graphics showing the as-built site situation. These photos were compared against the corresponding as-planned CAD images. Application cases in foundation excavation, refill, scaffolding and steel erection proved their methodologies to be convenient and effective in checking actual site progress against as-designed or as-planned models.

Memom et al. [12] identified the techniques, which were used in the construction industry for monitoring and evaluating the actual physical progress, and discuss the Digitalizing Construction Monitoring (DCM) model. The DCM model is an interactive system integrating 3D CAD drawings and digital images. The authors made a practical attempt to automate the process of producing as-built construction schedule by applying modern photogrammetry techniques to photographs and integrating with CAD drawings. The application of a DCM model in monitoring the progress would enable project management team to better track and control the productivity and quality of construction projects.

Quinones-Rozo et al. [13] explored the use of two image-based techniques to perform semi-automated tracking of excavation activities. An Enhanced Pattern Detection and Comparison (EPDC) technique was introduced to quickly identify changes in poor contrast excavation surfaces.

Luhmann and Tecklenburg [14] used site photos to measure 3D geometries of buildings adjacent to a construction site in order to preserve forensic evidence against potential construction-caused damage claims.

Kamat and El-Tawil [15] discussed the feasibility of using augmented reality (AR) to evaluate earthquake-induced building damage. In the proposed approach, previously stored building information is superimposed onto a real structure in AR. Structural damage can then be quantified by measuring and interpreting key differences between the real and augmented views of the facility. Proof-of-concept tests were performed in conjunction with large-scale cyclic shear wall. They measured and interpreted the drifts between the original walls in 3D CAD images and the actual wall specimens for post assessing any earthquake-induced building damages.

3 Issues on Accuracy

Photogrammetry has been seldom used actively to achieve a 3D model in the construction industry although it has been regarded as the most cost-effective, flexible, and portable approach in terms of getting a 3D model. Among many reasons keeping industry practitioners from actively using photogrammetry for 3D modelling is a doubt on the accuracy of the 3D model created from photos.

Burt [16] investigated factors affecting the accuracy of digital photogrammetry. From his study on historic adobe wall ruins located at Fort Davis in Texas, he demonstrated that photogrammetry is a suitable method for obtaining measurements of adobe erosion.

Randles et al. [17] compared traditional technique and photogrammetry for measurement of targeted damaged vehicle. The points on each vehicle were measured using both techniques, and compared. After all the calculations and comparisons, they concluded that both methods effectively measured the vehicle points, with a mean difference between the baseline and hands-on measurements of 0.6±1.4cm, and a mean difference between the baseline and photogrammetry measurements of 0.1±1.0cm.

However, a test conducted by Bhatla et al. [18] reported that a 3D model of a bridge created from photos was not accurate enough for construction professionals to use for decision-making. They created a 3D model of a 2,000ft bridge in southern United States, which was under construction, using 351 photos taken on the job site. They compared it against a 3D model developed manually from the 2D drawings. The average height of exterior girders, average distances between the holes for electrical fixtures, and the average length and width of the floor beams were compared between two models. They then found about 2 to 5% of differences between two models on the length of beams, height of exterior box girder, and distance between the holes for electrical fixtures. They concluded that photogrammetry was not suitable yet for modelling infrastructure projects.

4 Empirical Test

Our research team was wondering if current photogrammetric computer applications would enable us to create a decent 3D model that can be used by construction professionals for their decision-making. Seeking the answer for this question, our team decided to create a 3D model of an existing campus building using photos. The following figure shows the plan of the campus building we used for our test.

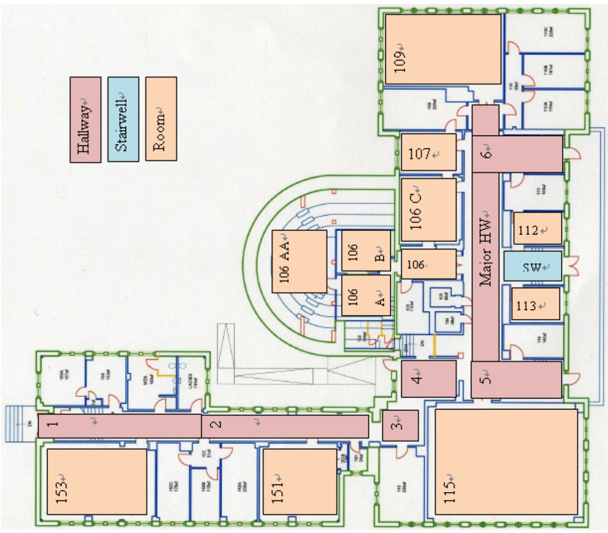

Figure 1 Floor plan of a building used for the empirical test

A digital single-lens reflex camera with 18-55mm lens attached was used for taking photos. The camera was placed on a tripod at multiple locations in the building, and photos were taken while the camera was getting rotated horizontally by 45 degrees and tilted vertically by 30 degrees in order to pickup all objects around the camera. As many as 1329 photos were taken for the test, and we spent a total of 278 minutes for taking those photos.

We then used Autodesk Stitcher to generate a panoramic image of the objects around the camera. Autodesk Stitcher is deisgned to generate a panoramic image automatacly. However, some photos were got getted stitched automatically, to some extent because of lack of texture and contrast of some objects. A total of 597 minutes were consumed for image processing.

For 3D modelling, we used Autodesk ImageModeler 2009. This application enabled us to pickup the boundary lines of building components including columns and walls. We drew lines on the edges of these objects and use them to create a 3D model of building components picked up by the camera at one location. We then map the photos on the surface of the 3D model. This process took a total of 87 minutes.

5 Accuracy of an Empirical Model

A total of 38 dimensions were extracted from our empirical model, and then compared with dimensions extracted from the 3D model created using CAD drawings. Differences between each dimension are defined:

- Difference = Dimension from CAD model – Dimension from photo model
- Difference (%) = Difference / Dimension from CAD model x 100

The following table presents some of differences we figured out.

Table 1 Differences in dimension between photo model and CAD model

Items	Photo model (m)	CAD model (m)	Difference (%)
1	2.39	2.39	0.11
2	5.05	5.02	-0.67
3	2.58	2.44	5.81
4	11.16	11.17	0.05
5	2.45	3.06	19.94
6	2.67	2.60	2.55

The mean and the standard deviation of all differences are 0.87% and 8.14% respectively. After eliminating the outliers with 95% confidence, the mean and standard deviation are -0.43% and 4.33% respectively. Then, the dimensions were categorized into four groups, and the mean and standard deviation for each group were calculated again to compare with each other. The result shows that when a length of a section is less than 3.81m (150 inches) or more than 10.16m (400 inches) the accuracy level of the model drops. The reason for this inaccuracy may be the result of distortion of panoramas, or the operator's mistakes when creating the model using panoramic photos.

6 Conclusions

In order to see if a 3D model created from photos is accurate enough for construction professionals to make decisions, we empirically created a 3D model of an existing campus building using 1,329 photos. It took 16 hours to produce a 3D model using these photos. A total of 278 minutes were consumed for photo taking, 597 minutes for stitching photos together, and 87 minutes for 3D modelling.

Dimensions were extracted from 38 difference locations in the photo model and compared with the dimensions extracted from the CAD model. It turned out that the differences between these dimensions were 0.87% in average. However, the accuracy level dropped when the length of the object was either shorter than 3.81 m or longer than 10.16 m.

Our test shows that a 3D model created from photos are fairly accurate for construction managers to figure out the status of job site. When the photo model and CAD model were both presented to industry professionals in the BIM CAVE (Computer Aided Virtual Environment for BIM), they indicated that they gained more sense of presence in the 3D model while walking though the photo model.

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