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Realistic Façade Texturing of Digital Building Models

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Abstract

The market related to 3D geospatial information is drastically increasing especially in the current internet or mobile environments. Many famous companies, such as Google and Microsoft, are already providing lots of 3D geospatial information in such environments. One of the interesting 3D geospatial information is 3D building information. However, most of the 3D building models produced by such companies are through the manual procedures. In this regards, this paper suggests a more automated framework for the realistic façade texturing of 3D building models. Linear features such as wire-frame of a building are used for geo-referencing of terrestrial images taken around the buildings in question. Afterwards, the texturing process is applied to the building models while considering occlusions and lens distortions. Conclusively, the results are shown in more realistic way through the proposed framework.

Keywords: *Geospatial information, 3D building models, Realistic façade texturing, Digital Building Models, Geo-referencing*

1. Introduction

With the recent technological advancements such as faster computation speed and more accurate sensory data acquisition [1-7], the automated virtual 3D city modeling has become more and more realistic. Many researchers all over the world have been working on this issue since 1990's. Approaches producing 3D building (or city) models only using photogrammetric data have been developed at the first stage. As different way of 3D building (or city) models, multi-source data integration has been suggested recently. One of the data integration approaches, the laser points are registered with an existing Digital Elevation Model or vector map, then merged with aerial LiDAR data [8, 9]. A novel approach for generating DBM (Digital Building Models) by integrating photogrammetric and LiDAR (Light Detection And Ranging) data over the areas with complex buildings was proposed by [10]. In this approach, the researchers suggested an approach with minimal or no user operations. More than accurate 3D building models either using photogrammetric data only or using the integration of different types of data, we need 3D virtual city modeling based on photorealistic textured DBM. Many famous companies, such as Google and Microsoft, are already providing lots of photorealistic 3D building models through Google maps, Google earth, and Bing maps. However, the 3D building models produced by such companies are mostly through the manual procedures.

In this regards, this paper suggests a framework for more automated realistic façade texturing of 3D building models. Linear features such as wire-frame of a building are used for geo-referencing of terrestrial images taken around the buildings in question. Afterwards, the texturing process is applied to the building models while considering

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occlusions and lens distortions. The other important part of the mapping strategy is to determine which images belong to which facades. This is a key step when we are dealing with a large image datasets. The generation of a synthetic texture for each façade using several images is also a crucial part and the ultimate goal. The stage will produce distortion-free textures with removal of unwanted occluding objects. The remaining parts of this paper will be 1) Study area and Datasets, 2) Photo selection, 3) Geo-referencing, 4) Visibility analysis, 5) Synthetic image generation, and 6) Conclusion. In the section for study area and dataset, the selected building, prepared images, and DBM will be explained. Afterwards, the efficient way of proper photo selection for each façade will be followed. The selected photo, then, will be geo-referenced to find its position and attitude. Since occlusion problem significantly affects the quality of the final results, the visibility analysis will be carried out and synthetic image for each façade will be produced. Finally, the concluding remarks will be addressed.

2. Study Area and Datasets

An engine eering building at the University of Calgary, Canada, is selected as a study area. The aerial photo and DBM of the building are shown in Figure 1 (a) and 1(b), respectively. DBM was generated using the method described in [10]. Airborne photogrammetric and LiDAR data were integrated to extract building rooftops and to produce building models. We also used a set of digital photos taken from a calibrated Canon Rebel EOS digital camera. When the photos were taken, the positions of the photos were recorded by a handheld GPS.

Figure 2 shows examples of terrestrial images taken around the selected building. The camera calibration procedure was carried out based on the approach suggested by [11]. This calibration procedure is based on Bundle Adjustment with Self Calibration (BASC) using the signalized targets on the test bed. Though the BASC, Interior Orientation Parameters (IOPs) of a camera can be achieved.

(a) (b)

Figure 1. Study Area; (a) Aerial Photo, (b) DBM of the Engineering Building at the University of Calgary, Canada

Figure 2. Examples of Terrestrial Images Taken by Canon Rebel EOS Camera

3. Methodology

The proposed framework can be divided into 5 steps: 1) Photo selection; 2) Geo-referencing; 3) Visibility analysis; 4) Synthetic image generation; and 5) Visualization. Figure 3 illustrates the main steps of the proposed framework.

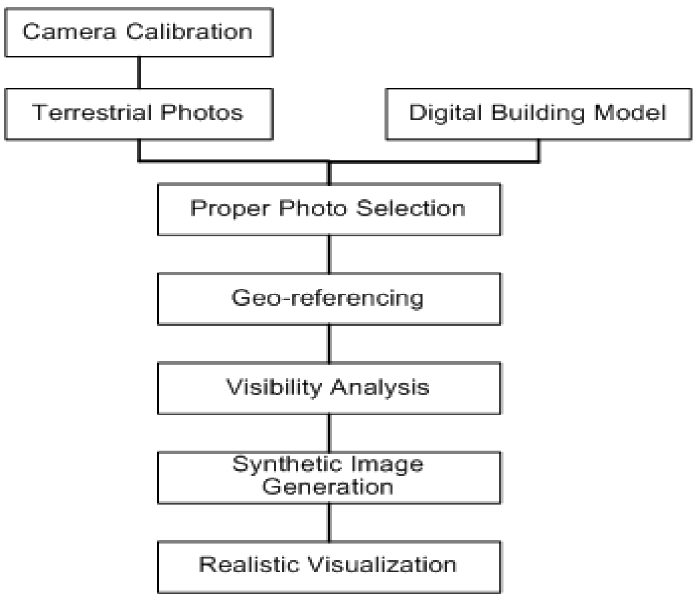

Figure 3. Workflow of the Proposed Framework

At the first stage, the photos will be pre-selected using the position information acquired from the handheld GPS. Afterwards, the operator will select the proper and necessary photos among the pre-selected photos. Such photos will be, then, geo-referenced based on the linear features which were acquired from the DBM. In this process, we will derive the accurate positional and attitude information for the selected photos. Since there are lots of occlusions especially when we are dealing with complex buildings, the visibility analysis should be carried out. Once the visibility analysis has been done, a synthetic image for each façade will be generated to minimize the occluded areas in the façade. Finally, the realistic visualization of the textured 3D building model will be implemented.

3.1. Photo Selection

Most of researches found in literature, uses photos directly geo-referenced by an integrated GPS-INSS system. Having this information will certainly provide a valuable assistance for photo selection and geo-referencing process. However, our goal is to develop a methodology which can deal with off-the-shelf digital cameras or even camera phones. Some of those come with a built-in GPS for fast geo-location. In this step, a photo selection method will be used to assist the operator to filter out the photos that do not belong to the façade in question. This process will reduce the effort to find the proper photos belonging to the façade in question. Certain size of a rectangle will be defined based on the parameters defined by an operator. The photos whose positions are located inside the rectangle will be automatically selected. Afterwards, the operator will finally choose the proper photos manually among the pre-selected photos.

3.2. Geo-referencing of the Selected Photos

Once the proper photos belonging to the façade in question are selected, Exterior Orientation Parameters (EOPs) of the photos are computed through the bundle adjustment procedures. Enough conjugate points are measured to tie the consecutive photos. Figure 4 shows the image measurement operation using two consecutive images. Moreover, linear features are measured on these photos to work as control information. The control information plays an important role when the absolute locations and attitudes of the relevant photos are determined. The linear features will be acquired from the given Digital Building Models.

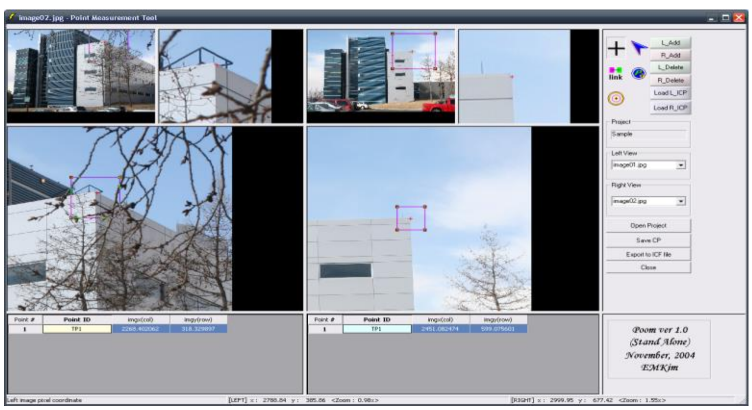

Figure 4. Image Measurement Operation

The geo-referencing process can be carried out as follows. First we have to set the transformation parameters from global to local (façade) coordinate system so that the absolute orientation is performed in the façade coordinate system. This would help estimating the initial approximation for the attitude rotation values. Once photos approximations are referenced to local (façade) coordinate system, the next step is to run the Bundle Adjustment to get precise EOPs for the photos relative to this local coordinate system. MSAT program will be used for processing this Bundle Adjustment. For this operation, image measurements of the tie points, image measurements of the control lines (façade borders), initial approximations of local (façade) coordinates of the tie points, and local coordinates of the control lines. To get the estimated approximation for the façade coordinates of tie points, we can directly project the points to the façade plane. The collinearity equations and plane equation (derived from façade) were used for this step as seen in Equations 1 and 2.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \lambda \cdot R^T \begin{pmatrix} x_i - x_p \\ y_i - y_p \\ -c \end{pmatrix} + \begin{pmatrix} X_0 \\ Y_0 \\ Z_0 \end{pmatrix} \tag{1}$$

$$aX + bY + cZ = d \tag{2}$$

where (X, Y, Z) are points projected on the façade plane, R is rotation matrix, (x_i, y_i, c) are IOPs, (X_0, Y_0, Z_0)are EOPs, and (a, b, c, d) are façade plane parameters.

Once the photos are oriented with respect to the façade coordinate system, they need to be transformed back to the Global coordinate system. Since the façade coordinate system has the same scale as the global coordinate system, this simplifies the transformation where it can be carried through using a 6 parameter transformation involving only 3 rotations and 3 shifts.

All the operational steps described above should be repeated for every façade polygon, until all photos are oriented with respect to the Global coordinate system. Since some photos might have multiple EOPs due to the individual façade operation, we might need to run a final least squares adjustment so that all photos will have one set of unique EOPs.

Another possibility to avoid such operational steps would be to use one Global operation where all photos can be processed in one BA procedure considering all façades in the process. This single operation might seem attractive at first but there are some considerations that should be considered. The advantages and disadvantages of two different operations (*i.e.*, local and global operations) are addressed as follows.

Table 1. Advantages and Disadvantages of Local and Global Operations

	Advantages	Disadvantages
Local operation	- Easy to estimate EOP approximations	- Many transformation involved
Global operation	- Implemented in one coordinate system	- Hard to estimate EOP approximations

3.3. Visibility Analysis

The visibility analysis method uses the information provided by a Digital Building Model. In general, a facade-by-facade analysis based on 3D ray tracing is performed to achieve a relevant selection. The method is based on standard techniques commonly used in computer graphics for visibility computations, namely the ray-tracing and z-buffering techniques [12]. These two techniques have now been used for decades and are very well-known in the computer graphics community. They can be optimized and accelerated via graphics card hardware.

Perhaps the most commonly used 3D-based method for visibility analysis, is the well-known z-buffer technique. In this method, each camera is analyzed individually. A set of candidate facades is first associated to the current camera as the 2D ray-tracing, using distance, half-plane and back-face culling criteria. The camera is then associated to a label image which identifies the facades seen by the camera, and also a depth image that indicates the distance from the camera perspective centre to the facades. Finally, after all the cameras have been processed, each facade can be associated to the list of cameras that can view it.

In this work we are going to use a 3D-based approach. This method combines the main advantages of the 2D ray-tracing and 3D z-buffering techniques: speed and use of 3D information. It is a 3D extension of the 2D approach based on ray tracing. However, the analysis is performed facade-by-facade rather than camera-by-camera. In this method, a set of candidate cameras for a given a facade, is selected using the same criteria as the 2D ray-tracing. We will include another restriction on camera selection based on viewing angle: cameras that too oblique to the facade plane are discarded. We expect to reduce processing time and improve texture quality by adding this additional restriction.

For each selected camera, the facade is projected on the camera plane. By doing this, light rays not intersecting the current facade are ignored. Then this projected polygon is subdivided to form a grid based on the image pixels. Each grid point defines a 3D ray passing through the camera center point. Those 3D rays are tested with respect to all the facades visible from the camera. Any ray intersecting a facade facet closer than the current one is discarded. The candidate camera is finally selected as viewing the current facade, if at least one of the rays has not been discarded. Figure 5 illustrates the concept of the visibility analysis.

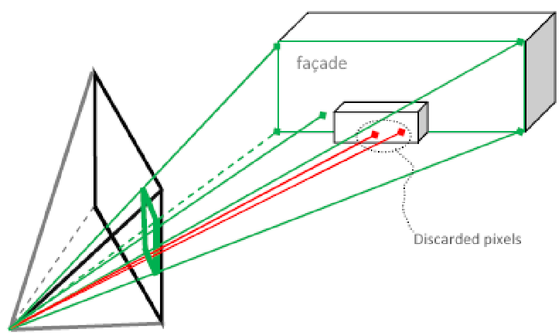

Figure 5. Concept of the Proposed Visibility Analysis

3.4. Synthetic Image Generation

Once the visibility analysis is done, a synthetic texture can be generated using the selected pixels within the photos. In this process, a distortion-free image will be generated and mapped to the respective façade as seen in Figure 6. The sampling distance (number of pixel) of the synthetic image is computed as simple ratio based on distance from the facade, focal length and pixel size in image space. The sampling distance will be computed for the first photo and all remaining photos will follow this resolution. Pixels having texture information coming from multiple images will be weighted by scale, viewing angle and image resolution. Missing pixels or occluded areas will be left blank. Specific cases of missing pixels within visible areas will be interpolated using bi-linear or bi-cubic convolution interpolation methods.

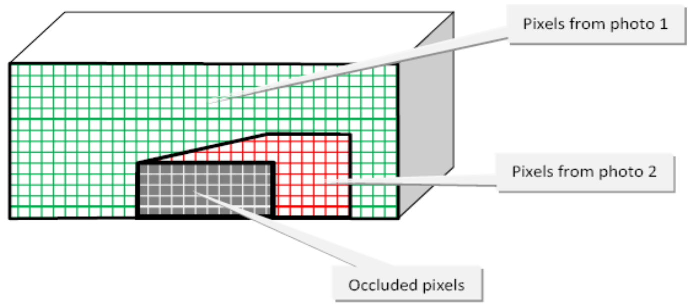

Figure 6. Synthetic Façade Image Generation with Multiple Photos

3.5. Realistic Visualization

Once the synthetic texture image has been produced for each façade, the final process is to export the building model for realistic visualization. Since we have a digital building model, and the corresponding synthetic texture image, the texture mapping can be easily defined. The file format, either CityGML or Collada, can be used to export the building model with texture image. The visualization can be carried out using any software that can import the file format of choice. Figure 7 shows the final output of the photo-realistic visualization of 3D building model.

Figure 7. Photo-realistic Visualization of 3D Building Model

4. Concluding Remarks

This paper proposed a framework for realistic façade texturing of digital building models. To avoid manual processes as much as we can, pre-selection of proper photos for each façade, visibility analysis, synthetic texture image generation were suggested in automated ways. Moreover, linear features derived from Digital Building Models were utilized in the geo-referencing process. The automated ways of the process will help deal with a large image datasets. The occlusion problem, which occurs in case of complex buildings, was resolved through the process of visibility analysis. As future work, the authors will try to generate fully automated approach for realistic 3D building model visualization.

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