Texture Generation and Mapping Using Video Sequences for 3D Building Models

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Abstract Three-dimensional (3D) building model is one of the most important components in a cyber city implementation and application. This study developed an effective and highly automated system to generate and map (near) photo-realistic texture attributes onto 3D building models using digital video sequences. The system extracted frames with overlapped textures of building facades and integrated them to produce complete texture images. Interest points on the extracted video frames were identified using corner-detectors and matched with normalized cross-correlation for seamless stitching. Shadows and foreign objects were identified and removed with morphological algorithms and mended by mirroring neighborhood textures. Completed mosaicked texture images were mapped onto corresponding model facets by linear or parametric transformation. Test examples demonstrate that the developed system can effective generate seamless photo-realistic texture images and correctly map them onto complicated 3D building models with high efficiency.

Keywords: texture mapping; video mosaic; 3D building model; cyber city; visualization

1. Introduction

Cyber city is one of the emerging topics in 3D geoinformatics. A cyber city resembles the layouts, activities and functionalities of a real city in a computer generated environment. In real world, buildings are the most ubiquitous objects. Similarly, building model is one of the most important components in a cyber city implementation. The geometric outlines of buildings can be reconstructed from remote sensing data effectively using a variety of algorithms [1-3]. However, currently, most reconstructed models do not have sufficient or accurate texture attributes about the exteriors or facades of buildings. The lack of accurate textures not only makes 3D building models less realistic, it may also fail to provide necessary information in certain applications of cyber city.

Shading models with pseudo textures is a commonly adopted approach in visualization [4], but does not represent true building textures. For realistic texture mapping of 3D building models, using images acquired with digital cameras is a viable approach [5-9]. However, for a large-scale cyber city implementation, it will require a significant amount of images for a complete texture mapping. Digital video (DV) is a more efficient source of acquiring raw texture images. Therefore, this study developed a highly automated system for photo-realistic textures generation and mapping with video sequences for cyber city visualization and applications.

2. Texture mapping of 3D building models

Video data have been used in the virtual environment for visual effects or city model visualization [10-12]. To use DV for realistic texture mapping of 3D building models, a few issues must be addressed, including:

- *Photogrammetric correction: establishing relationships between texture images and models.* One way to accomplish this task is to acquire camera parameters with additional equipments [13]. A few algorithms were developed to reconstruct original or related camera parameters, projection geometry and pose, such as using correlations of overlapped images [5], by vanishing points [14], or vision-based modeling [15]. Another approach for photogrammetric correction of raw texture images is to register a group of correlated images to a common image space [8, 16].
- *Mosaicking: stitching multiple images to generate a complete texture that is continuous in geometry and color shading*. Photogrammetric correction should have addressed the geometric issues, but the colors and shadings of all frames should also be integrated. Histogram match or equalization is popular in adjusting color distributions of images into the same range [17]. However, directly applying it to close-range DV data may cause serious misrendering. Weighted blending algorithms, such as alpha blending (feathering) [18], pyramid blending [19] or gradient domain stitching [20], are more likely to generate smooth and seamless results.
- *Removal and mending of non-interested regions.* Shadows and regions blocked by other buildings or foreign objects such as trees and cars. should be identified and removed from texture mosaics and mended with correct or similar texture blocks.
- *Transformation: mapping generated texture mosaics to model facets*. This is a transformation from image or texture space to object space. Depending on the photogrammetric correction, this can be done by pro-

jective texture mapping [5, 7, 14, 15] or linear transformation in either object space or parametric space as described in [8].

3. Methodology

This developed texture generation and mapping system can be categorized into several phases as described below.

3.1 Preprocessing

The raw texture images were collected using a Sony digital video camcorder (Sony DCR-DVD201). Video frames were extracted from video sequences to generate a texture mosaic. Each extracted frame image had a 40% to 60% overlap with adjacent frame image.

3.2 Image registration

This was to transform a group of texture frames of the same facade to a common image space. Two types of registration were performed. For regular (planar) texture images, they were registered to building model directly. The registration was done by interactively identify four roof and ground corners on the image. Their coordinates were obtained from building layout CAD files and digital terrain models. A few points in between were then interpolated from roof-ground point pairs. These points were then used as tie points to register the image to building model using the eight-parameter algorithm and least-squares-fitting. The registration result is shown in Fig.-1.

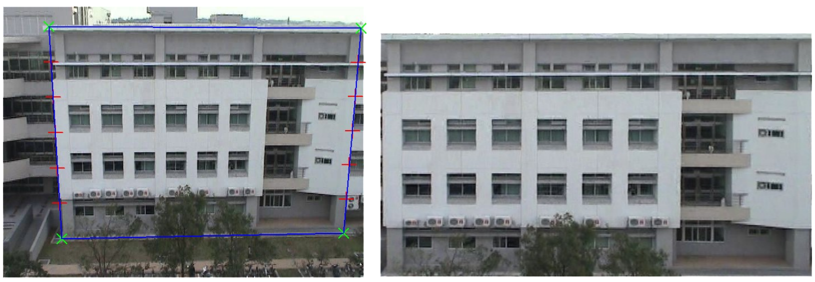

Fig. 1: Registration of a regular-shaped façade to model.

For irregular-shaped (non-planar) facades, a two-step polynomial fitting registration algorithm [8] was applied to transform them to a common image space (but not the object space).

3,3 Mosaicking

First, Harris Corner Detector [20] and non-maximum suppression was applied to each frame to generate interest points (Fig-2). Then, tie points were identified by matching interested points with a simple but effective algorithm. Since adjacent frames in a video sequence had almost identical viewing conditions, the overlapped region of two frames should have high correlation. Examining a pair of extracted frames a time, the relative displacements (in image coordinates) of the two frames should be identical whether using the left or right frame as the reference. This can be used to preliminarily match the detected corner points.In addition, because the two frames had 40% to 60% overlaps, a Normalized Cross Correlation (NCC) operation was carried out on every pair of adjacent frames, using the ending 40% of the left frame as the target window and the whole image of the right frame as the search window and 0.9 as the correlation threshold, to further identify highly correlated (matched) points as the tie points. Fig-3 shows an example of the matching result.

Fig. 2: Detected corner points.

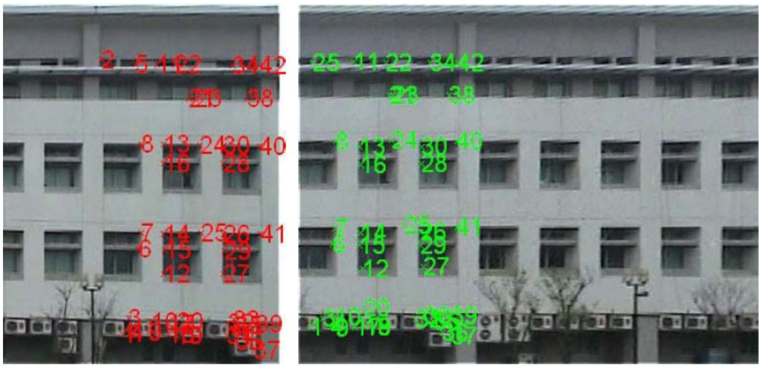

Fig. 3: Interest point matching using image displacement criteria and NCC.

After tie points were identified in all frames, they were merged together to form a texture mosaic. The blending algorithm demonstrated in [8] was used to adjust the colors and shadings in overlapped areas. A mosaic of two frames is displayed in Fig-4. As displayed in the figure, the mosaic is continuous in geometry and seamless in colors and shadings.

Fig. 4: Mosaicking of two overlapped frames.

3.4 Removal and mending of non-interested regions

The developed system utilized Greenness Index (GI) and morphological operations to remove non-interested regions. GI was used to separate areas blocked by green vegetation; while morphological "close" (i.e. dilation then erosion) and "bottom-hat" (i.e. subtracting original form closed image) operations segmented texture images according to specified structuring element. The removal of non-interested regions using these algorithms is demonstrated in Fig-5.

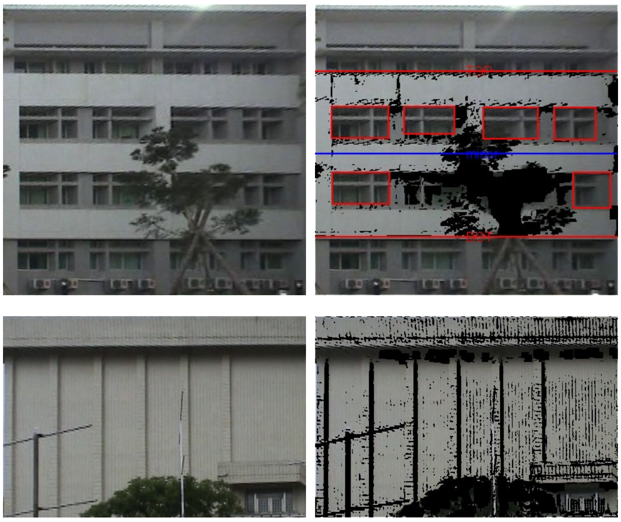

Fig. 5: Removal of non-interested regions.

This study also developed a self-mending algorithm. Most building facade textures have repeated patterns (e.g. windows). Therefore, it is possible to identify the areas of repeated patterns and its mirroring axis, so the removed regions can be refilled by mirroring correct texture blocks. The mirroring axis was also identified using a combination of image morphology and region growing. Fig-6 shows the mirroring axis of a complete mosaic and the patched up image. After texture mosaics of all building facades were generated and patched up, they were than mapped onto corresponding model facets.

Fig. 6: Mirroring axis of a texture mosaic (top) and the result after patching up non-interested regions.

4. Experimental Results

The developed texture generation and mapping system was applied to a block in NCU campus to test its performance. In addition to texture images acquired using DV, 3D polyhedral building models and DTM data were obtained for the experiment. Fig-7 displays two perspective views of the testing area. Fig-8 simulates a street view of the same area.

As demonstrated in these figures, the developed algorithms successfully generated texture images for building facades and correctly mapped them onto corresponding model facets. The correction and mosaicking algorithms were effective in generating texture mosaics with continuous geometric outlines and seamless color shadings. Most of non-interested regions were removed using the GI and morphological operations and patched up reasonably. (Only parts of the lower texture areas are still blocked by trees or other small objects.) More importantly, the developed system requires little human interaction except when identifying the initial four tie points for photogrammetric corrections and measuring the image displacements when adjusting irregular-shaped facade textures. The rest of the algorithms are highly automatic.

5. Conclusions

This study developed a highly automated system to perform photo-realistic texture generation and mapping using video sequences for 3D building models. The system employed corner detection algorithms to identify interest points. The interest points were then matched based on a image displacement restriction and normalized cross correlation measures. The mosaicking algorithms were effective in generating complete texture images that are continuous in both geometry and color domains. Non-interested regions could also be automatically removed with GI and morphological operations and then mended using mirroring of correct texture blocks, where the mirroring axis on each mosaic was also identified automatically using image morphology and region growing. The resultant 3D building models consisted of more completed and accurate attributes and had photo-realistic appearances. More importantly, the algorithms were more efficient comparing to photograph-based texture generation and mapping systems. This should be a valuable addition to large-scale cyber city implementations and applications.

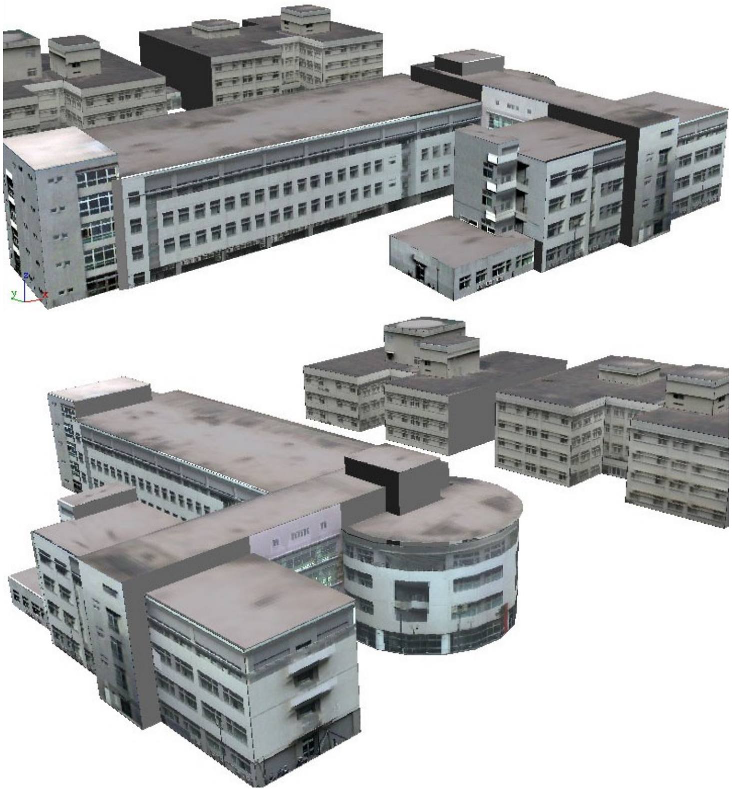

Fig. 7: Two perspective views of the test area.

Fig. 8: Simulation of a street view in the test area.

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