LARGE SCALE TEXTURE MAPPING OF BUILDING FACADES

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ABSTRACT:

A virtual 3-dimension city model is a sophisticated application of geoinformatic systems as it represents layouts, activities and functionalities of a real-world community. To enable human users to better visualize their living spaces, a virtual reality city model must be both immersive and accurately re-created. Visualization of city models in such environments is a combination of many challenging and laborious tasks, one of which is the texturing of building models façade. To improve the photo-realism and textural information of the building model façade, close-range digital photographs of buildings are taken at oblique angles and used to texture the building models. This paper will show that by taking oblique views of buildings, we are able to perform large scale texture mapping on multiple buildings models and improve the overall workflow of the entire façade texture extraction process. Registration of the digital images must be carried out to obtain the images' extrinsic and intrinsic parameters before accurate texture mapping can take place. Spatial distortions due to irregularly shaped façade polygons are introduced during the texture extraction process and a method was devised to overcome this problem. A test example will be used to demonstrate the system of performing large scale texture mapping using minimal amount of close-range photographs.

1. INTRODUCTION

A 3-D city in virtual reality is a sophisticated application of geoinformatic systems as it is a representation of layouts, activities and functionalities of a real-world community. It is an integrated effort in the fields of computer graphics, remote sensing and engineering to achieve a feasible, yet convincing representation of the city in the virtual world. An accurate and immersive virtual reality city model would enable the users to better visualize their living spaces interactively with greater detail and thus model human activity more intuitively and efficiently than before. All these would depend on the accurate reconstruction on both the 3-D terrain and building models as well as the correct texture mapping of model surfaces.

Current generation satellite imagery coupled with Rational Polynomial Coefficient (RPC) can be used to accurately estimate 3-dimensional building information (Grodecki, 2001). In the case of IKONOS stereo images, the accuracies are within 1 metre horizontally and 2 metres vertically hence acceptable for use in urban mapping whereby landscape and building objects are usually bigger than 3 metres (Grodecki and Dial, 2001). With the advancements in building extraction techniques, we are able to extract a large number of buildings in a short period of time. For example, using a technique develop at CRISP (Huang and Kwoh, 2007), we are able to extract about 60 buildings per hour in an urban area using a single IKONOS image coupled with RPC and building shadow information.

Remote sensing data can provide limited texture information to the extracted building models as this is restricted by the sensor look angles. Very often, only the building model tops and certain building model facades are textured and the building model facades extracted from satellite imagery are pixelated due to the lack of resolution and texture information (Huang et al., 2006). This is because the represented skew area of building façade which can be seen from the satellite imagery is relatively small when compared to the actual size.

3-D virtual reality city model visualization platforms use OpenGL or DirectX to effectively render the buildings models and ground terrain using hardware acceleration. When texture information of the building facade is not known, it is a common practise to assign a pseudo texture to the building model instead (Beck, 2003). Although this provides a better presentation of the building model, it is not ideal as it does not portray the true characteristics of the building façade. Such pseudo representations of the building facades, makes the overall visualization system less realistic and less useful. Hence, to improve the overall photo-realistic quality and usability, we texture the building façade with terrestrial digital photographs taken using commercially available cameras. However, the process of allocating and mapping the appropriate texture from terrestrial photographs to correct building façade is both laborious and time-consuming. To address this issue, we have developed a system which implements a semi-automated process for the large scale texture mapping of the building façade and this will be presented in this paper.

2. TEXTURE MAPPING OF BUILDING FACADE

The texture mapping process of building façade involves the transformation from image space to building model space. There are two methods of carrying out the transformation. Firstly, the forward mapping method selects the appropriate texture polygon from the image and maps it to the matching building façade. Conversely, the reverse mapping method

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transforms the building façade to fit within the image according to the image's extrinsic and intrinsic parameters. The forward mapping method is a more tedious process as the user is required to provide the outline of each façade on the image before texture mapping can be carried out, hence this method is not suitable for our application. On the other hand, the reverse mapping method has a greater potential for workflow optimization as the façade outlines can be projected automatically onto the image, provided the full set of camera parameters are known. The reverse mapping method will be used as the basis for texture mapping of building façade in our system.

2.1 Camera calibration and image orientation recovery

The projection of the building model façade onto the close-range digital image is done using collinearity equations (McGlone, 2004). In order to project the façade accurately, it is important to obtain the extrinsic and intrinsic parameters of the digital camera.

The intrinsic parameters of the camera comprises of the pixel size, focal length, image size and lens distortion. The focal length and image size is readily available in the image's Exchangeable Image File Format (EXIF) while the sensor size information can be found in the specific camera manufacturer's specifications. Lens distortions are assumed to be negligible due to the distances of which the target object is away from the exposure station.

The extrinsic parameters of the camera are the metric position and orientation when the image was taken with respect to the world reference frame. The extrinsic parameters can be recovered with a combination of a closed form space resection (Zeng and Wang, 1992) and classical non-linear space resection based on collinearity (McGlone, 2004; Wolf, 2000) using just 4 control points to match object space to image space. The closed form space resection approximate solution provides an initial estimate for the classical non-linear space resection method to solve for the precise extrinsic parameters.

2.2 Culling of non-front facing and occluded façade

As the reverse mapping method of projecting building model coordinates onto the image is used, non-front facing façade will be projected onto the image as well. This is not acceptable as the non-front facing façade will cause erroneous texture mapping of the building models. To prevent this, we will have to decide whether the projected façade is front facing or non-front facing before texturing can be done. The building façade world coordinate points are arranged in a clockwise manner to denote a front facing façade as shown in Figure 1. After projection onto the image, the winding of a front facing façade should still be clockwise while a non-front facing façade will possess an anti-clockwise winding, thus effectively culling all non-front facing façade.

It is our intent to carry out large scale texturing for the building façade, hence we try to capture as many buildings possible on a single image. This can be done by moving the exposure station as far away possible and keeping an oblique angle to the intended buildings to be textured. In the process, it is inevitable that complete occlusion of some buildings might take place, resulting in the erroneous texturing of those occluded building façade. A simple polygon collision test (Miller, 2000) was devised and all front-facing façade were tested. If 2 different

façade are fully overlapped, the façade nearer to the exposure station will be chosen to be textured.
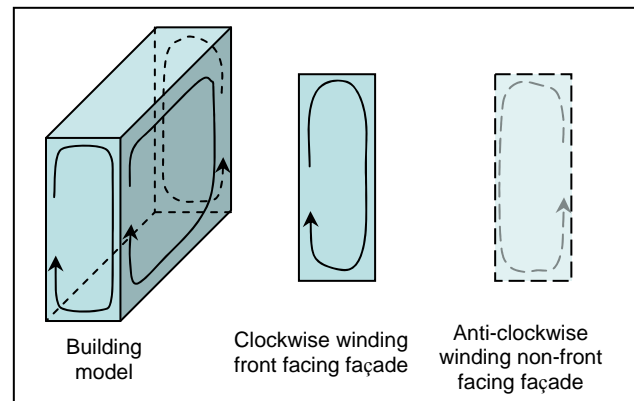

Figure 1. Differentiating between front facing and non-front facing facade

2.3 Geometric correction of skewed façade textures

Oblique view images of the buildings are more effective in large scale texture mapping as compared to frontal planar view images. It is because they are able to capture more views of the building and reduce the number of photographs required. However, a skew factor will be introduced to the mapped façade after being projected from the building model. The resulting texture polygon outline is irregularly shaped and the irregularities are highly dependent on the angle of which the image was acquired.
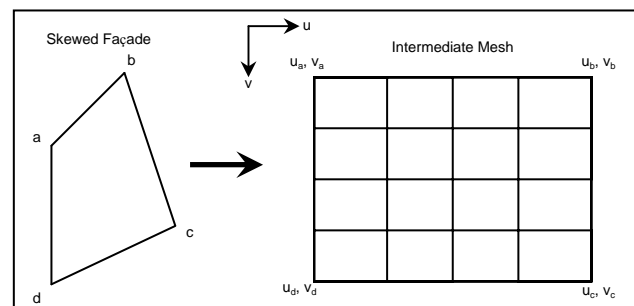

Figure 2. Adjustment of skewed facade texture

We devised a method in OpenGL to correct the geometric distortion due the irregularly shaped polygon. As shown in Figure 2, the skewed façade texture is mapped onto an intermediate rectangular mesh with sufficient resolution using the façade position coordinates (a, b, c & d) to obtain the appropriate corner texture coordinates (u_a, v_a, u_b, v_b, u_c, v_c, u_d, v_d) for the mesh. The other points within the mesh are assigned texture coordinates through linear interpolation of the 4 corner texture coordinates. The mesh is subsequently rendered via OpenGL and the resulting frame buffer is a geometrically corrected façade texture.

2.4 Colour balancing of extracted façade textures

After texture mapping is carried out, the resulting building model would consist of a mosaic of different images acquired possibly under different illumination and physical conditions.

This results in differences in colour and contrast on different sides of the building model and it becomes necessary to reduce these differences in order to improve the overall visual effect of the textured building model. Colour balancing of different close-range images can be done by histogram matching using statistical methods (Gonzales and Woods, 2002) to reduce the difference. It is given by,

$$^{Bal}\mathrm{Im} = \left[^{Orig}\mathrm{Im} - {}^{Orig}\mu\right] \times \frac{^{Re\,f}\sigma}{^{Orig}\sigma} + {}^{Re\,f}\mu \qquad (1)$$

where
^{Bal}Im = colour balanced image
^{Orig}Im = original image
$^{Orig}\mu$ = statistical mean of original image
$^{Orig}\sigma$ = standard deviation of original image
$^{Ref}\mu$ = statistical mean of reference image
$^{Ref}\sigma$ = standard deviation of reference image

Colour balancing needs to be carried out for each pixel on the respective colour bands.

3. RESULTS AND DISCUSSIONS

The test data set consist of building models extracted from a stereo-pair of IKONOS satellite imagery using SOCET and the respective building model tops were draped with the IKONOS image as illustrated in Figure 3. A series of close-range ground images were acquired using a few commercially available cameras ranging from Digital Single Lens Reflex cameras (DSLR) to simple Point and Shoot (PNS) digital cameras. The images were registered to obtain the extrinsic and intrinsic parameters using the methods described in the previous section and texture mapping was carried out.
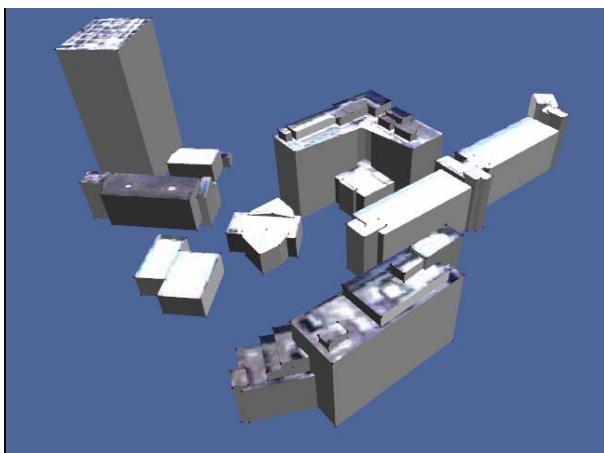

Figure 3. Test building models with pseudo façade textures

Figure 4 shows a projected façade highlighted by the red boundary on a digital photograph pertaining to one of the building models used in our test data set. The resulting extracted façade is shown in Figure 5. The left image of Figure 5 is rendered from a high resolution mesh whilst the right image is rendered from a low resolution mesh. It can be observed that the geometric distortions caused by using a skewed façade texture were not fully corrected on the low resolution mesh.

Some aliasing effects were introduced into the image and these were especially evident at the seam lines between mesh triangles. These distortions are a by-product of resampling during OpenGL texture mapping transformations. There are many techniques to alleviate the aliasing effect and the method of using a finer mesh as shown in the left of Figure 5, is able to negate such errors and extract a geometrically corrected façade texture.

Figure 4. Image with a single façade highlighted for texture mapping

Figure 5. Geometrically corrected facade texture from Figure 4. High resolution mesh (left). Low resolution mesh (right).

Figure 6. Test building with multiple facade textures

Figure 6 shows the test building which has been textured using geometrically corrected and colour balanced façade textures. This particular building model required 3 digital photographs to provide enough views to texture the entire building model. As

compared to the pseudo-textured building, the previous has a better photo-realistic effect and provides more relevant textural information.

Both Figure 7 and Figure 8 show examples of large scale texturing of building models taking place. The feature of culling occluded façade was turned off and all projected façade were being displayed, less the non-front facing ones. It is observed that using a small number of digital photographs, we are able to texture map a relatively large number of façade belonging to different buildings models.

Figure 7. Large scale texturing of multiple buildings

Figure 8. Large scale texturing of multiple buildings

Figure 9 shows different perspective views of the test building model data set with actual façade textures using 10 digital photographs taken on different occasions. We observed that the majority of the extracted façade textures were correctly aligned with the building model with very little spatial distortions. The transitions between adjacent façade on each building were smooth, without much variation in colour and contrast. A small number of façade did not have a texture of acceptable quality; hence they were assigned a pseudo blank texture for consistent representation instead. In general, we are able to demonstrate that large scale texture mapping of buildings is an economical approach of efficiently producing photo-realistic façade textures for 3-D virtual reality city models.
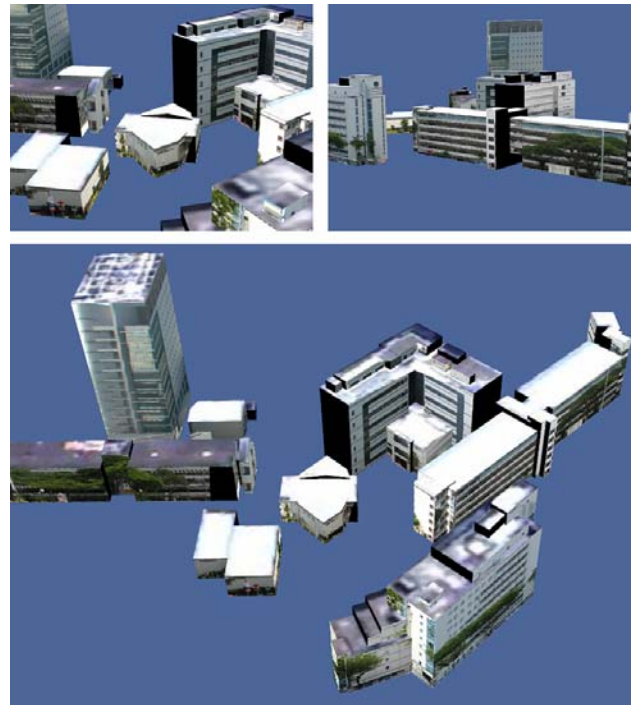

Figure 9. Perspective view of test building models with actual facade textured

4. CONCLUSION

This study developed a system for the large scale texture mapping of building façade in the virtual reality city model environment. We are able to extract and generate façade textures from multiple digital photographs with great accuracy and efficiency. Digital photographs taken in the oblique view will reduce the number of photographs needed but introduce a skew distortion in the process. We have demonstrated that such view dependent distortions can be properly corrected to produce coherent façade textures.

In conclusion, real landscapes are highly complex structures, often covering very large areas and its visualization often challenging and laborious. As such, by taking the above mentioned measures, we are able to improve the overall photo-realism effect of the city model environment with greater ease.

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