PRODUCTION METHOD OF ACCURATE 3D URBAN MODELS WITH DIGITAL PHOTOGRAMMETRY

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Abstract. A convenient method for creating accurate 3D urban models without expensive survey equipment is developed by introducing digital photogrammetry. As a matter of logic, the 3D models for urban landscape simulations are expected to limit errors to several dozen centimeters. The proposed method is examined in order to reproduce the actual urban landscape and to provide accuracy that is sufficient to meet the theoretical requirement.

Keywords: downtown; landscape; simulation; VRML

1. Issues

With the advance of information technology, methods for describing urban space have rapidly evolved from traditional analog media such as maps, drawings and scale models, into new digital media such as CAD, GIS, and CG. As evidenced by programs such as Google Earth, these data have been constructed on an increasingly large and varied scale through computer networking technology. Currently, 3D urban landscapes simulated with these digital media are prevalent in the architecture and urban planning industries.

However, there remains a significant technological gap in accuracy. Although planned architectures or famous landmarks can be depicted in great detail based on actual measurements, surrounding buildings are usually represented by simple columnar shapes created by set calculations (e.g., extracted from the basic floor height * number of floors) from less-accurate border lines traced on analog maps or from aerial photos.

Therefore, there is a possibility that simulated landscapes created with these imbalanced data will differ substantially from real landscapes. To effectively evaluate proposed architectural and urban plans with landscape simulations, especially in downtown areas where volume and shadow constraints are severe, a convenient method by which the landscape in its entirety can be described consistently and accurately is needed. For this purpose, an extensive method using aircraft-based Light Detection and Ranging (LIDAR) technology is currently being used for the automatic generation of simulations. However, it is impossible to reproduce shapes of sufficient accuracy and economic feasibility using this method.

2. Objectives

In the present paper, a convenient method for creating accurate 3D urban models without expensive survey equipment is proposed by introducing digital photogrammetry. The accuracy of the proposed method is also examined.

3. Scale and Accuracy

In comparison with analog media and digital media, the logical relation between scale and accuracy can be illustrated in Figure 1.

In the case of analog media, as the scale gets smaller, the accuracy becomes worse, because even a slight error is expanded in proportion to the scale. In fact, the surveying specification in Japan describes the range of error (horizontal location) as 0.25 m (0.5 mm * 500) on a scale of 1/500, 0.7 m (0.7 mm * 1,000) on a scale of 1/1,000, and 1.75 m (0.7 mm * 2,500) on the most popular scale of 1/2,500. Therefore, the analog maps on a regional scale that is used extensively in the field of architecture and urban planning potentially contain the above-described error.

In the case of digital media, theoretically, accuracy can be maintained regardless of scale, because data are expressed numerically. (Strictly speaking, accuracy is not always maintained in case of the cancellation error in floating-point calculation.) Actually, additional details down to the millimeter are used in the architectural design business to meet the requirements of function, structure, and institution. Therefore, architectural drawings obtained by CAD are of the highest precision and, in principle, should not contain errors. (Of course, some errors may be observed in their construction process)

In landscape simulations using CG, 3D urban models are constructed using data having completely different accuracies. In particular, it is much more difficult to get information related to the vertical direction for existing buildings. Therefore, alternatively, estimations (e.g., basic floor height * number of floors) have been used without foundation. This is essentially the same method that is used to make analog scale models using Styrofoam, and the associated errors are incomparably worse than those associated with maps. Even if they are made to look realistic, with texture mapping, their volumes actually differ from the actual shapes.

If these 3D urban models are observed by bird’s-eye view on the scale of a topographic map, the errors might not be a big problem. Considering the resolution of produced images, even at hi-vision resolution (1,920 * 1,080 pixels), for a topographic map (1/2,500) covering an area of approximately 2 km * 1.5 km, one pixel would be approximately equivalent to 1.5 m * 1.5 m square. The size of pixels is not far from the errors of maps.

However, if these models are observed from ground-level on a scale of architecture and urban space, their errors are a serious problem. According to an estimate using the standard view angle, even though one pixel is more than 1.2 m * 1.2 m square from a distance (more than 2.5 km far away), one pixel is approximately 0.7 m * 0.7 m square at an intermediate distance (400 m to 2.5 km) and less than 0.2 m * 0.2 m square when viewed from a nearer vantage point (less than 400 m). Therefore, the errors of data are directly reflected in produced images. However, the highest accuracy is not requested for 3D urban landscape simulation. Even if the model is depicted accurately based on architectural drawings or measured drawings, the differences beyond resolution are rarely reflected on produced images.

According to the above discussion, the 3D models currently used for urban landscape simulations are expected to limit errors to several dozen centimeters.

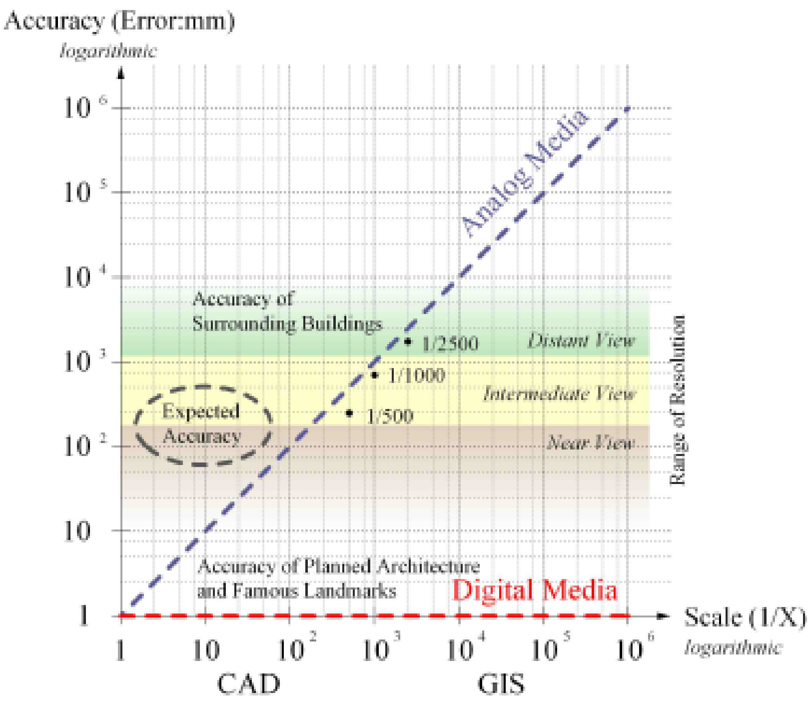

Figure 1. Relation between scale and accuracy.

4. Digital Photogrammetry

Digital photogrammetry is a technology that allows photogrammetry, which is performed using an analog stereoplotter, to be performed using a computer. Photogrammetry is an established technology in the field of cartography, and most maps supplied by the Geographical Survey Institute of Japan are produced from aerial photos using this method. However, great skill is required in order to operate the analog stereoplotter, and the necessary equipment is very expensive. Therefore, it is generally not possible to use this method. On the other hand, digital photogrammetry software can be operated with comparative ease, and the necessary equipment is relatively inexpensive. Therefore, digital photogrammetry has spread rapidly in the field of surveying.

The basis of photogrammetry is binocular vision, and more than two pictures of the measurement object taken at a distance are required (Figure 2). To simplify the problem, if these two pictures are taken on exactly the same picture plane, a measurement point could be calculated using the following formula in the system of coordinates with their origin at the focal point of the camera of the first picture:

$$
\begin{aligned}
x &= d * X1 / (X2 - X1 - d) \\
y &= d * Y1 / (X2 - X1 - d) \qquad (1) \\
z &= f * (X2 - X1) / (X2 - X1 - d)
\end{aligned}
$$

where *X1*, *Y1*, *X2*, and *Y2* are coordinate values on the picture plane, *d* is the relative distance of cameras, and *f* is the focus length.

However, the actual relation among these elements is not as simple as that described stated. It is usually the case that the relative distance of the cameras (*d*) is unknown and each picture plane is also inclined. Therefore, these values are estimated by the least-squares method from the correspondence relationship of multiple points on the pictures. This process is called orientation in photogrammetry.

It is also necessary to preliminarily measure the distortion of the lens on the camera to be used. In particular, wide-angle lenses, which are generally used to take architectural pictures, have heavy distortion on the periphery, and coordinate values must be adjusted to account for this distortion.

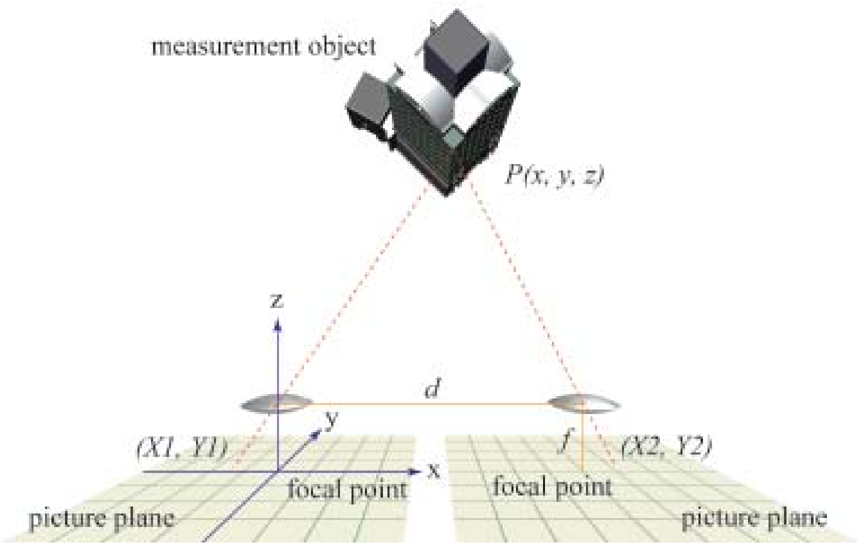

Figure 2. Basis of photogrammetry.

5. Process of Constructing Urban Models

Downtown Tsukuba City was selected as the research zone, where approximately 50 apartment buildings, office buildings, commercial facilities and multistoried parking lots are present within an area of approximately 0.5 km^2. In addition, large-scale developments are taking place with the opening of a new railway in 2006, and the urban landscape simulation is expected to reflect the rapid pace of change.

The process of constructing 3D urban models is illustrated in Figure 3.

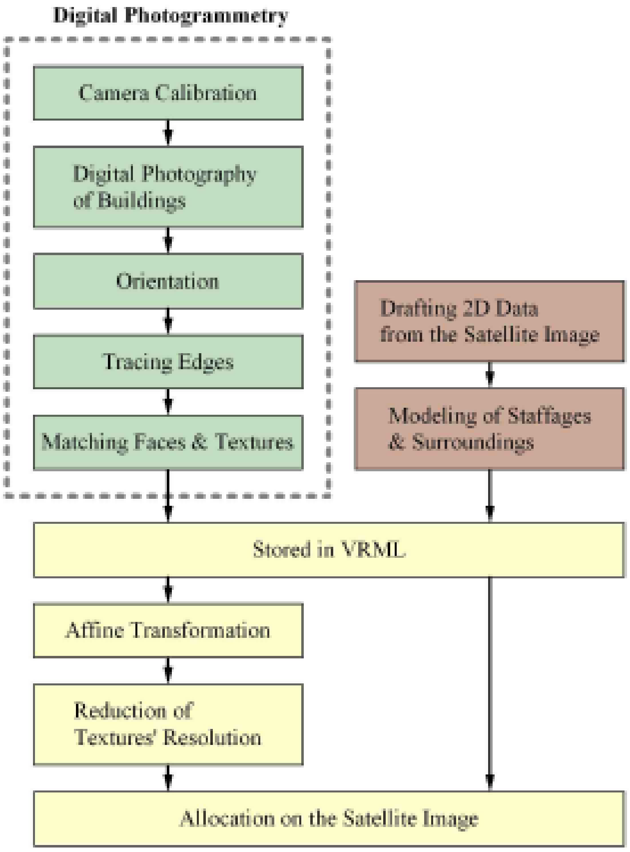

Figure 3. Process of constructing 3D urban models.

First, digital pictures (4,064 * 2,704 pixels) of each building are taken at ground level in order to constitute stereo pairs. The shooting directions are very important for later calculations. After a great deal of trial and error, a typical square-shaped building was found to require pictures to be taken from 11 directions: eight directions (2 * 4) in front of each elevation surface for the stereo pair pictures of the cardinal directions, and three diagonal directions to adjust the coordinate systems of the contiguous elevation surfaces with each other (Figure 4). Of course, fewer pictures (four diagonal directions at minimum) can be used, but the next orientation would become severe and the produced models would barely be acceptable for urban landscape simulation because of the expanded distortion of their textures clipped being removed from the pictures.

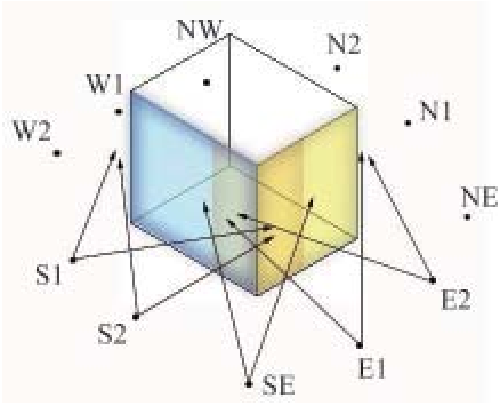

Figure 4. *Shooting directions.*

Second, orientation points are defined on the stereo pair pictures, which are then used to derive the camera positions and specify the coordinate system of these images. To perform accurate photogrammetry, particular marks are usually placed on the measurement object as orientation points before taking pictures. However, placing these marks on wall surfaces is simply impractical, and so characteristic points of buildings were selected instead. Higher-accuracy 3D models can also be produced if the camera positions and orientation points are not derived but are actually measured with survey equipment in the field. However, the process of constructing urban models requires that sufficient accuracy be ensured with a convenient method, and not minimization of the error.

Next, 3D shapes are derived by tracing edges and matching faces and textures by referencing the relevant stereo pairs (Figure 5). Sometimes, due to restrictions of the surrounding environment, the necessary pictures cannot be taken from all directions, and in such cases not all elevations surfaces of the building can be traced. In addition, since pictures are taken at ground level, it is impossible to reproduce hidden areas such as rooftops. However, since these areas cannot be seen in the same way through the urban landscape simulation from ground-level, this is not a significant problem.

Figure 5. *3D shape by tracing edges and matching faces and texture.*

Finally, each 3D datum is stored in VRML format and located on a high-resolution satellite image by affine transformation to complete the entire 3D urban space (Figure 6). This is necessary because each building is assigned an individual coordinate system supposed based on their individual images, and these buildings are reproduced in relative scale, rather than absolute scale. In addition, reducing the resolutions of textures removed from pictures is sometimes necessary for real-time walkthrough simulations.

The survey works generally require a group of engineers who are skilled in operating survey instruments, whereas the abovementioned process can be performed from beginning to end by a non-skilled individual.

Figure 6. Completed 3D urban model.

6. Evaluation and Conclusion

A comparison of the simulated image and the photographic image from the same viewpoint on the ground is shown in Figure 7. The building at the right in the photographic image is under construction and so could not be reproduced in the 3D urban model. Therefore, a faraway apartment building appears in the simulated image. With this exception, at first glance, there appears to be little difference between the two images.

Figure 7. Simulated image (left) and photographic image (right)

To verify the accuracy of this method, 3D urban models are compared with the actual dimensions of famous landmark architecture (Table 1). As a result, the average point errors were confirmed to be 23 cm, which is quite precise compared with commercial data produced from LIDAR (within 1 m). This accuracy meets the theoretical requirement mentioned above. In addition, the characteristic concavity and convexity in the appearance of actual buildings can be replicated using this method.

Table 1. Verification of accuracy.

Lower Part				Upper Part			
actual	measure	error	ratio	actual	measure	error	ratio
18.40 m	*18.21m*	*-0.20 m*	*-1.05 %*	*38.40 m*	*38.64 m*	*0.24 m*	*0.64 %*
18.40 m	*18.38 m*	*-0.02 m*	*-0.10 %*	*38.40 m*	*38.71 m*	*0.31 m*	*0.80 %*
13.60 m	*13.23 m*	*-0.37 m*	*-2.69 %*	*33.60 m*	*33.39 m*	*-0.21 m*	*-0.63 %*
13.60 m	*13.47 m*	*-0.13 m*	*-0.96 %*	*33.60 m*	*33.18 m*	*-0.42 m*	*-1.25 %*

In conclusion, by introducing digital photogrammetry, the expected accuracy for 3D urban models could be achieved. However, it is still difficult to reproduce rounded shapes and trace edges hidden by vegetation. This problem is an issue for future research.

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