RECONSTRUCTING ROAD AND BLOCK FROM DEM IN URBAN AREA

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ABSTRACT

This paper targets the reconstruction of 3D urban models consisting of realistic architecture models and different objects on a ground surface. When reconstructing 3D urban models it is necessary to handle a diverse range of complex structures and objects, and the models must be efficiently and precisely formed. Onto these models will be projected the textures acquired from the actual objects. Research into building reconstruction has been active, but there is little research on structures other than buildings. This paper describes a new approach to reconstructing models for roads, intersections and blocks, that is to say, ground surface objects in urban areas.
When reconstructing road, intersection and block models there are three problems. The first is the separation of roads and blocks. The second is the accurate determination of surface model parameters. The third is the construction of the optimal model, that is, both the model degree and the model error is minimum. Against the first problem, we use digital 2D maps and separate roads and blocks by matching the edge points of buildings acquired from DEM to the building shapes on maps. Against the second problem, we extract only scattered elevation points to avoid obstacles such as buildings, trees inside the block and cars on the roads, and determine the surface model parameters by analyzing the partial cross sections of roads and blocks, using the MDL principle and heuristic construction knowledge.
Finally we show an example of 3D urban models of many buildings on a ground surface. Onto these models are projected realistic textures.

1 INTRODUCTION

1.1 What's 3D urban model

3D urban model is needed in the fields of urban planning, urban investigation, and urban disaster simulations. Because realistic texture is projected onto each model, the 3D urban model is also expected to be used more often in the conservation of houses, reproduction of urban views, and forming the Digital City. Moreover, we expect to use the 3D urban model as the infrastructure for the Geometric Information System (GIS) in urban areas. This system will build a better urban life for us. Examples include traffic control, evacuation guidance, route guidance, and local information. For putting these goals into practice we need detailed 3D urban model, especially road and block models, that is to say, ground surface models are very important. They make it possible to simulate disaster scenarios such as inundation, earthquake, fire, and traffic. By extracting polygonal ground surface models we can project realistic textures onto the models to create walkthrough worlds.

1.2 State of Object Extraction from DEM

There are two main techniques that realize automatic object extraction for the recovery of 3D urban models. One extracts buildings from multiple aerial images (Baillard, C. et al., 1999). The other extracts buildings from DEM (Digital Elevation Map) data acquired by airborne laser scanning systems. In recent years laser scanning systems have become a very attractive way to acquire 3D data. Especially when mounted in a helicopter, such systems can produce high-density height data revealing detailed information about the presence and shape of buildings. By using a helicopter we can efficiently and easily acquire 3D data. Compared to the height points determined by matching aerial images, the airborne laser scanning systems yield very precise and reliable measurements. Therefore, we utilize DEM data acquired by an airborne laser scanning system.
Several papers have been presented that deal with building extraction from DEM. The pioneers used parametric building models and determined the shape and position parameters by fitting the models to the DEM (Haala, N., 1994). They also reconstructed prismatic building models with flat roofs using the Minimum Description Length principle (Haala, N., 1997). They then utilize the known ground plan information to improve model accuracy. The ground plan of a building is subdivided in rectangles. Several models of building primitives are fitted to the height data within each rectangle. Merging the models of the primitives using the results of best fitting forms the building models. Moreover, they extracted planar roof faces from DEM. In this case, building plans were utilized to determine the orientation of the

roof faces in a robust manner and the reconstruct the topological relationships between the faces. We presented an approach for the reconstruction of prismatic building models with flat roofs using surface analysis and Hough transformation (Horiguchi, S. et al, 1999). However, urban models should not include only buildings but also roads, blocks, sidewalks and roadside trees and so on. The first two roads and blocks, very important for producing useful urban simulations.

1.3 Our Approach

This paper describes a new approach to reconstruct road, intersection and block models: we use the road network on the digital 2D map. In the road network, a node means intersection, a link means a road. A block is extracted as an area enclosed by roads and intersections. When reconstructing road, intersection, and block models there are three problems. The first is the separation of road and block areas. The second is the determination of road and block model parameters. The third is reconstruction of optimal model, that is, both model size and the error must be minimized. These three problems are settled by the process flow shown in Figure 1.

First, we separate road and block areas by matching the edge points of buildings extracted from DEM on the digital 2D map.

Second, we extract the surface model primitives of roads, intersections and block.

Third, we assume that the intersection surface models as flat, and reconstruct the road surface models using the Minimum Description Length (MDL) principle. A road surface model reconstructed by this principle has both minimum model degree and the model error. We reconstruct block surface models as polygons delineated by the vertices of the adjoining intersection models and road models.

Fourth, we combine surface and building models. Building models are reconstructed using the technique presented in (Horiguchi et al., 1999).

Finally, we project the realistic texture acquired from aerial video images onto the models of buildings, roads, intersections, and block surfaces. We proposed a technique that yields exact texture mapping by comparing the polygons of 3D models to the texture shapes within aerial video images (Horiguchi et al., 1999). We try to ensure robust, high quality texture projection. In order to determine the capture system parameters, video camera motion, position, and orientation are determined using a Differential - Global Positioning System.

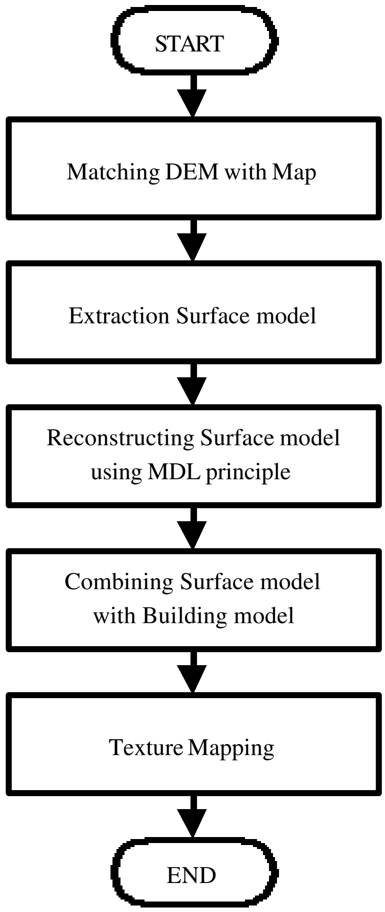


Figure 1. Block Diagram

In a trial, 3D urban models of roads, intersections, block surface models and building models are recovered by our new approach.

2 RECONSTRUCTING OF ROAD AND BLOCK SURFACE MODEL

2.1 Matching DEM with Digital 2D map

We match DEM to a digital 2D map using the building shape information in the digital 2D map in order to extract road, intersection and block areas from DEM. Although DEM and the digital 2D map have grid values based on common coordinate system together, it is not easy to match them. When matching DEM to a digital 2D map by using only grid values, the displacement errors become very large because the DEM is inaccurate in the horizontal plane. Therefore, this paper describes an approach that minimizes the errors.

We previously proposed a technique to divide DEM data into three surface types: Flat type, Slope type, and Boundary type by using Gaussian and Mean curvature (Horiguchi et al., 1999). In this case, the point sets of Boundary type represent the contours of buildings, and corresponds building shapes on the digital 2D map. Therefore, our approach minimizes the distance between points of Boundary type and lines of building shape by offsetting the DEM alignment on the horizontal plane.

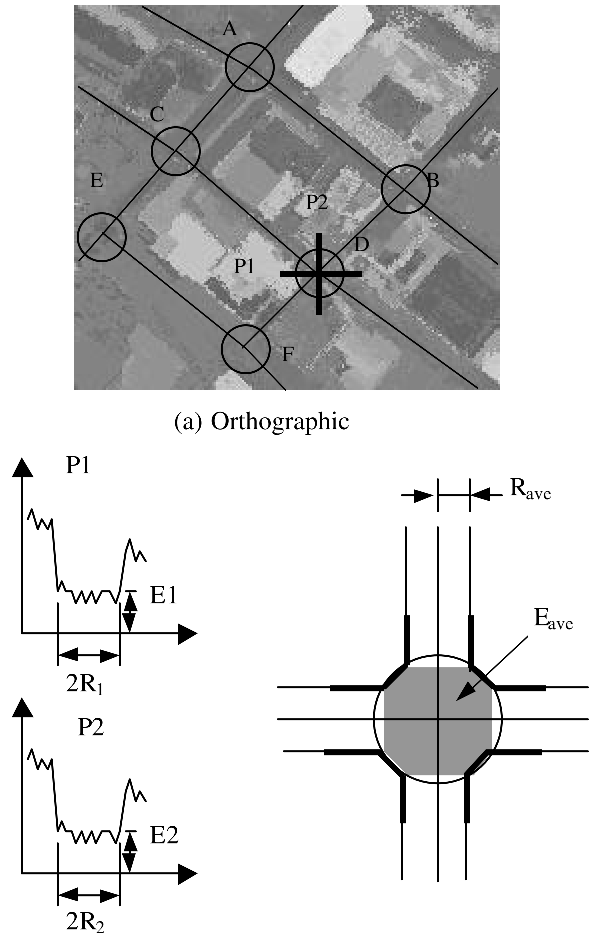
Figure 2 shows an example of DEM - digital 2D map matching. In Figure 2, the left image shows the Boundary point set extracted from DEM. Gray points are Boundary type entities. The right image shows the corresponding digital 2D map. It is obvious that characteristic structures are well matched.

(a) Image of Boundary point set extracted from DEM (b) Digital 2D map

Figure 2. Result of matching DEM with map

2.2 Extracting Intersection surface model and Reconstructing

Figure 3 shows how to extract an intersection with 4 roads. Top image shows the road network on the DEM. A circle means a node, that is to say, an intersection. A line means a link, i.e. a road. P1 and P2 are lines used to acquire the cross section of an intersection. The middle image shows typical cross sections as extracted by P1 and P2. We use heuristic construction knowledge that intersections are almost flat and lie between tall buildings. Based on this knowledge we acquire the basic parameters, that is to say, the radius and elevation of each intersection. Intersection radius and elevation, Rave and Eave in Figure 3, are acquired by analyzing the DEM. Radius Rave is the average of R1 and R2. The intersection is taken as the polygon formed by the 8 points shown. Elevation Eave is the average of E1 and E2. Most intersections in urban areas are flat, so our intersection model is reconstructed as a flat plane.



(b) Cross section (c) Intersection model

Figure 3. Reconstructing Intersection surface model

2.3 Extracting Road surface model

Figure 4 shows how to extract a road between two intersections: C and D. Top image shows the road network on the DEM. Road length L is acquired as the distance between intersection C and intersection D. P1 and P2 are the lines used to acquire road cross sections. We use heuristic construction knowledge that roads lie between tall buildings and that roads is virtually flat across their width. Based on this knowledge, road width, W1 and W2, and road elevation, E1 and E2, are acquired by analyzing the DEM. Road width Wave is the average of Wi (i=1,2,…, n). Road elevation is the data set of Ei (i=1,2,…, n). In this case, data set Ei includes errors since it is based on DEM data, which tends to be noisy. Therefore, we need to calculate an approximate line that suppresses the errors. We approximate the lines by applying the MDL principle.

2.4 Reconstructing Road surface model using MDL principle

The models created by the above processes tend to be impractical because the amount of data used to form a model, its description length, is extremely large. Obviously there is a tradeoff between description length and error, the discrepancy between the actual object and its model. The bottom image in Figure 4 shows the cross section of road surface models of interval intersection C and D. In this case, road elevations Ei (I=1,2,…,n) are given even if the road is perfectly flat as the data set includes noise.

The following shows our approach to approximating a road surface as a polynomial. The cross section data of DEM take the form Z_i (i=1,2,…,n), where n is the number of data points. If Z_i contains noise that has normal distribution with mean 0, and variance σ_o then the information source model

$$\mathbf{X}(S_{k_m}^{(m)}) = \{ p^n_{\theta^{(m)}} \}_{\theta^{(m)} \in S_{k_m}^{(m)}} \qquad (m = 1,2,\cdots,M) \tag{1}$$

is expressed by the follows equation.

$$p^n_{\theta^{(m)}}(z^n) = \frac{1}{(\sqrt{2\pi\sigma_o})^n} \exp\left\{ -\frac{1}{2\sigma_o^2} \sum_{i=1}^{n} (z_i - f_i^{(m)})^2 \right\} \tag{2}$$

$$f_i^{(m)} = a_1^{(m)} + a_2^{(m)} i + \cdots + a_{k_m}^{(m)} i^{k_m - 1} \tag{3}$$

$$S_{k_m}^{(m)} = \{\theta^{(m)} = (a_1^{(m)}, a_2^{(m)}, \cdots, a_{k_m}^{(m)}) \mid a_{k_m}^{(m)} \neq 0\} \tag{4}$$

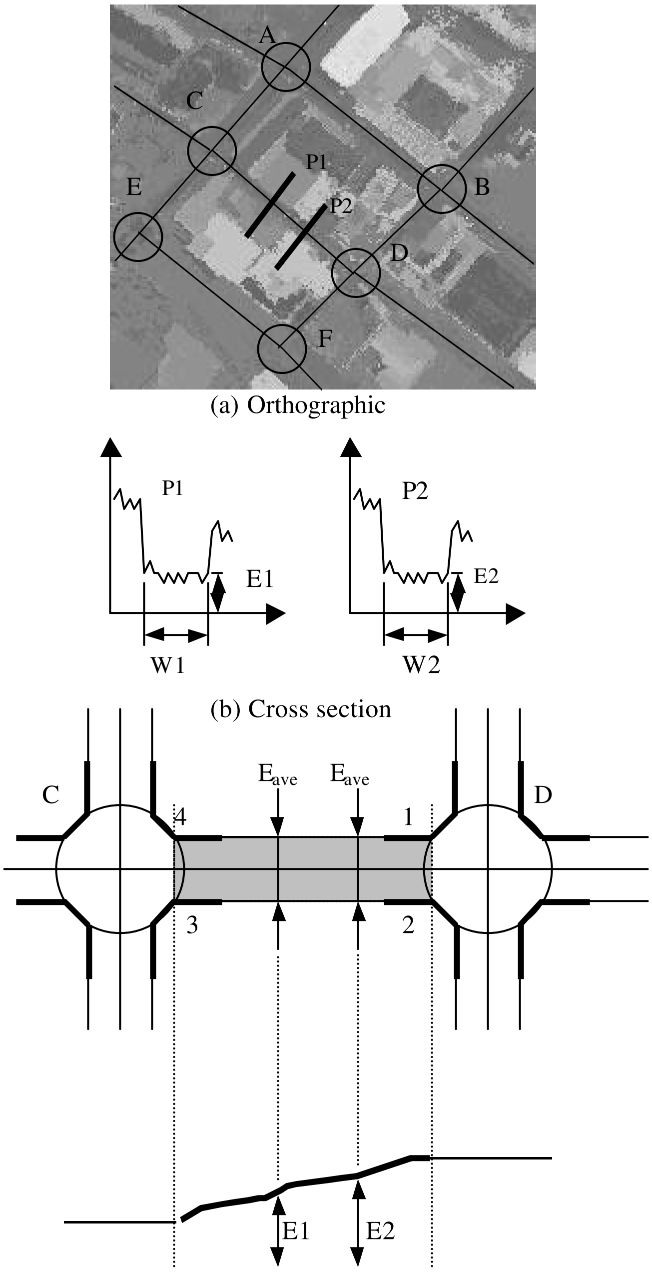


Figure 4. Reconstructing Road surface model

Equation (2) means probability distribution, normal distribution. Equation (3), (4) are polynomials of degree m. if k_m=m, M>>n then the code word length is expressed as follows.

$$\begin{aligned} l_R^{(m)}(z^n) &= -\log_K p^n_{\hat{\theta}^{(m)}}(z^n) + \frac{k_m}{2}\log_K n + \log_K M \\ &= n\log_K(\sqrt{2\pi\sigma_o}) + \frac{1}{2\sigma_o^2}\sum_{i=1}^{n}(z_i - \hat{f}_i^{(m)})^2 + \frac{m}{2}\log_K n + \log_K M \end{aligned} \tag{5}$$

In equation (5) first and third functions are constant. Therefore the cost function related to the degree of the model is as follows.

$$\frac{1}{2\sigma_o^2}\sum_{i=1}^{n}(z_i-\hat{f}_i^{(m)})^2+\frac{m}{2}\log_K n \qquad (6)$$

Equation (6) exhibits a minimum, which represents the optimal degree of the model.
In the case of figure 4, the degree of the approximate line is 2 (m=2), that is to say, the approximate line is straight, and we reconstruct the road surface model by treating intersections C and D as one polygon model whose length is L, width is Wave; vertices are 1, 2, 3 and 4.
If the actual road is actually straight, the road surface model should be a polygon model such of degree one like model (a) in Figure 5. But, if the actual road changes in height often, its model should consist of several polygons like model (b). In this case we face the problem of determining how many polygons the optimum surface model should consist of; we optimize each surface model by applying the MDL principle.
The degree of the polynomial calculated by the MDL principle correlates to the number of polygon connecting points. If degree m is 2 then the number of connecting points is 0. If degree m is 3 then the number of connecting points is 1. Consequently the number of connecting point is expressed m-2.

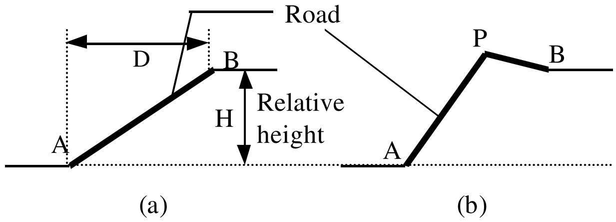


Figure 5. Different road surface model

We reconstruct road surface models based on the number of connecting points. This allows us to reconstruct the optimal surface model based on the optimal degree acquired by the MDL principle.

2.5 Reconstructing Block surface model

Finally this section describes the reconstruction of block surface models by using the road network contained in the digital 2D map. This technique extracts block surfaces as areas enclosed by road surface models and intersection surface models. In Figure 4 and Figure 5 the rectangle enclosed by intersections A, B, C and D corresponds to a block surface model.

3 RECONSTRUCING OF 3D DIGITAL CITY

We combine the surface models with building models. The building models were reconstructed using our previous technique (Horiguchi et al, 1999). Building model position was decided on building position as indicated in a digital 2D map. Building model height was calculated from the points of contact between building and surface models. Each model acquired by our approach, that is to say, Road, Intersection, Block and Building models, agrees with the object figure information shown on the digital 2D map.
A previous paper described how to project textures onto surface models and building models (Horigutchi et al., 1999). The visible points on the image that correspond to the vertexes of surface model are computed by the technique of perspective projection.

4 EXPERIMENTS

4.1 Results of reconstructing Surface model

Figures 6 and 7 show a block surface model and road and intersection surface model, respectively.

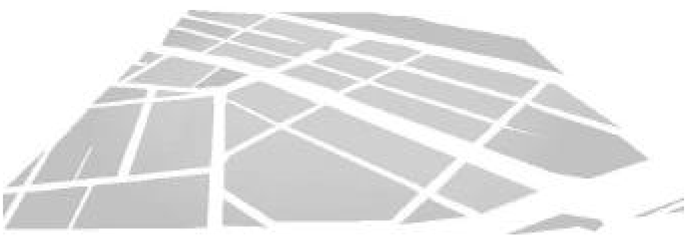


Figure 6. Results of Block surface model

The gray indicates the Block surface model. The vertices of the Block surface model touch the vertices of Road and Intersection surface models.

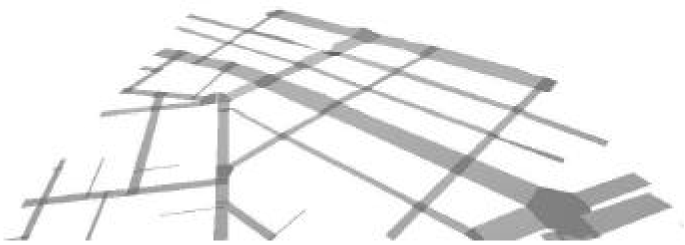


Figure 7. Results of Road and Intersection surface model

The road surface models are shown in light gray, while strong gray represents the intersection surface models. The road surface models were mostly flat.

4.2 Results of reconstructing 3D Digital city model

Figures 8, 9 and 10 show an image of the input DEM, the appearance of the reconstructed 3D digital city model and 3D digital city projected realistic texture onto the top of the buildings, respectively. This DEM covered an area of 500m by 500m. Elevation data was acquired on a 50cm grid. Therefore there were 1,000,000 elevation points. And this DEM is acquired from the first pulse of laser scanning system. These DEM values express the top of objects.
One characteristics of this 3D digital city is that it makes the 3D model correspond to objects in the digital 2D map on a one to one basis. Consequently this 3D digital city model is very easy to use in several simulations and GIS applications.

Figure 8. Input DEM

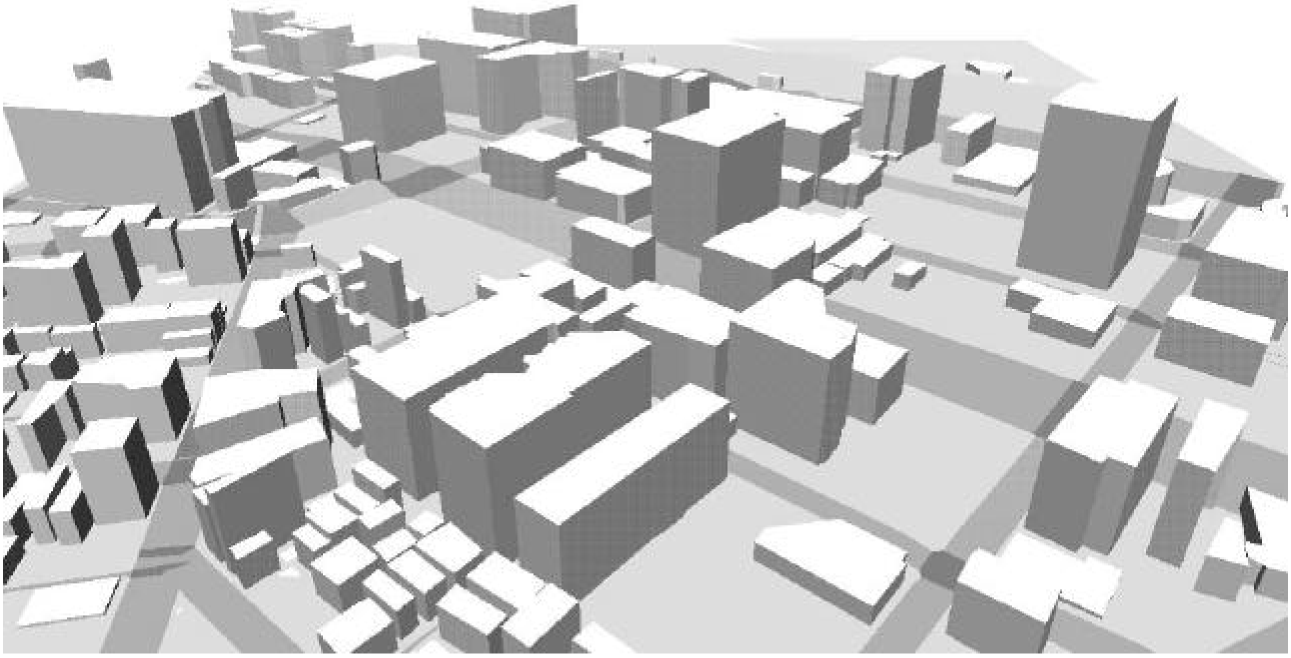


Figure 9. 3D digital city model reconstructed by our approach

Although the roof shape of buildings is flat, the height of buildings is variable. 3D urban view is sufficiently reproduced.

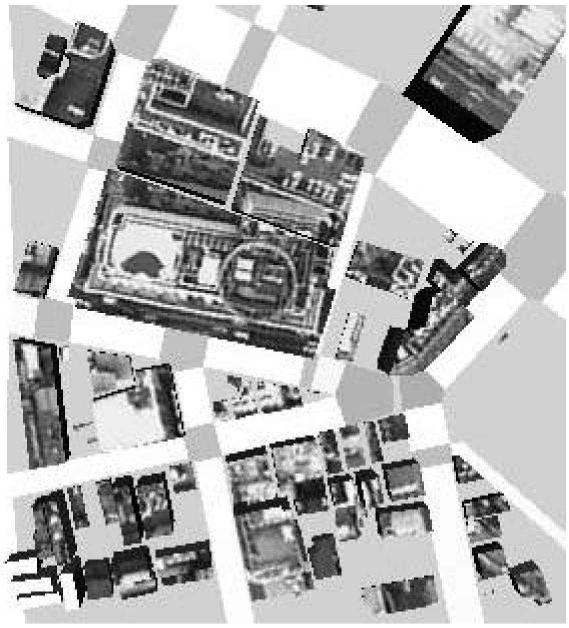


Figure 10. 3D digital city model projected texture acquired from video imagess

And if this 3D urban model is projected realistic texture then reality is improving. Although we only project texture onto the top of buildings, our approach can be projected onto intersection, road and block surface too.

5 CONCLUSIONS

We proposed a new technique to reconstruct surface models (block, road and intersection surface models), and a way to combine the surface models with building models. Especially we showed to reconstruct the ups and downs road and block surface as well as continuous ground surface by using road network in the 2D digital map.

We reconstructed a part of an urban area using the proposed approach. Our conclusions are as follows.

Minimizing the distance between points of Boundary type and lines of building shape is effective in matching DEM with digital 2D map information. In this case, the Boundary type points are acquired by extracting Gaussian and Mean curvature components.

We apply the MDL principle to optimize the road models. The optimized surface models are compact and easy to use.

The building shape shown on digital 2D maps is effective in acquiring object shape.

The proposed technique allows the reconstruction of the 3D digital city for urban simulations.

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REFERENCES

Horiguchi, S. et al., 1999, Recovering 3D urban model using Range data and Sequential Images, UM3, pp.

Baillard, C. et al., 1999, AUTOMATIC LINE MATCHING AND 3D RECONSTRUCTION OF BUILDING FROM MULTIPLE VIEWS, International Archives of Photogrammetry and Remote Sensing, vol.32, part 3-2W5, pp. 69-80

Haala, N., 1994, Detection of buildings by fusion of range and image data, International Archives of Photogrammetry and Remote Sensing, vol.30, part 3/1, pp. 341-346.

Haala, N., 1997, Acquisition of 3D urban models by analysis of aerial images, digital surface models and existing 2D building information, SPIE Vol. 3072, pp.212-222.

Haala, N. et al., 1998, 3D urban GIS from laser altimeter and 2D map data, International Archives of Photogrammetry and Remote Sensing, vol. 32, part 3/1, pp. 339-346.

Masaharu, H. et al., 1999, EXTRACTION OF BUILDING SHAPES FROM LASER SCANNER DATA USING REGION SEGMENTATION METHOD, Proc. ISPRS, Vol.32, Part 5-3W12, pp.37-42.