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City Range Data Analysis

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Abstract In order to realize more precise geometrical models of existing buildings, range images are used to represent the geometrical information of the façades of existing buildings. First, the range images of existing buildings are acquired using laser scanners mounted on a data acquisition vehicle which runs along the street. After removing obstacles, edge detection based segmentation and histogram are used to locate the vertical patterns from the range image of the buildings. Then by matching the patterns from the range image with that from a digital map using a pattern matching algorithm based on dynamic programming, the range image corresponding to the façade of a building can be determined. Precise geometrical information of the façade of the buildings can be obtained from its corresponding range image.

Keyword: City range data, Digital map, Edge based segmentation, Pattern matching, Dynamic programming

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1. Introduction

In recent years, the demand for 3D model of the real world has increased rapidly. 3D model representing existing objects or scene are very useful in many fields [1]. In this paper, we focus on obtaining geometric model of existing buildings in an urban area and generating a 3D city map.

The height of buildings and geometric shapes of the rooftops of buildings can be determined by using laser scanners mounted on helicopters or planes. But the facades of the buildings in an existing 3D map are constructed from video images, and precise geometric models of the facades are still unavailable. Instead of video image, range image of the facades of the buildings is used in order to acquire more precise geometrical information in our research. In order to make 3D city map, existing 2D digital map, for example [3], can be used to reduce error and cost.

First, the facades of the buildings are scanned by line scan laser scanners mounted on a data acquisition vehicle that runs along the street. After removing obstacles and edge detection based segmentation, the city range image is matched with a 2D digital map using pattern matching algorithm based on dynamic programming. According to this matching result, the range images corresponding to the façades of the buildings can be determined. Precise geometrical model of the facades of the buildings can be obtained from the range images.

The remainder of this paper is organized as follows. Some related works and our basic analysis principles are introduced briefly in section 2. Our analysis of city range image is introduced in section 3. Our experiment is described in section 4. The conclusion of this paper is in section 5.

2. Related Research and Basic Analysis Principles

It is well known that a range image is an array of depth values for points on an object from a specific viewpoint, and a range image can represent geometrical information more precise than a video image. So instead of video images, range images are used in our research to realize more precise geometrical model than previous research.

A city range image means a range image of a street in a city area. In general, buildings, trees, cars, electrical post, and pedestrians exist in a city range image. In this paper, we focus on the buildings in a city range image.

In this section, acquisition of city range image is described in subsection 2.1. The reason why a data acquisition vehicle is used can be found in this subsection. Analysis of a city range image is introduced in subsection 2.2. And range image segmentation, which is used in extracting a range image of one building from city range image, is introduced in subsection 2.3.

2-1 City Range Image Acquisition

According to position of scanners, methods of acquiring city range image can be classified into two categories: airborne [4,5,6] and ground based [4,7,8,9,11].

In the airborne methods, laser scanners are mounted on helicopters or planes. These methods are good at acquiring information about rooftops and height of buildings. But image resolution is coarse. In general, these methods are not suitable for acquiring information about the lower part of buildings in an urban area, because the lower part of buildings is often hidden by other buildings and becomes invisible from the scanners in the air.

In the ground based methods, laser scanners are on the ground or mounted on a data acquisition vehicle. These methods are good at acquiring information about the lower part of buildings' surfaces and street scenery. Building façades are our main concern, so the ground based category is chosen.

Because of the size of the cities, it is impossible to cover all buildings in one scan, so multiple scans are needed in acquiring city range image. The ground based methods for obtaining multiple scans can be further divided into two categories: stop-and-go scanning and continuous scanning [8].

In stop-and-go scanning, scanners scan buildings from fixed viewpoints. The scanners move to the next viewpoints after finishing scanning from the current viewpoints. High image resolution can be achieved in stop-and-go scanning, but a long scanning time is necessary [10].

In continuous scanning, scanners are mounted on a data acquisition vehicle. The scanners scan buildings when the vehicle remains moving [4, 7, 8, 9]. Because of this continuous movement, image resolution is lower than stop-and-go scanning. But a wide area can be scanned quickly.

In order to make a 3D city map, it is necessary to acquire range image in a wide area. Stop-and-go scanning becomes impractical because too long scanning time is needed. So continuous scanning is used in our research.

2-2 Model Generation from City Range Image

In stop-and-go scanning, multiple range images of the same building can be acquired from different viewpoints using high resolution 3D laser scanners, such as Cyrax scanner. These range images can be registered to generate a high resolution geometrical model of the building [2, 10].

In continuous scanning, the scanners scan the buildings along the road when the data acquisition vehicle moves, so high scanning speed is necessary [4, 7]. Line scan type laser scanner is one of the solutions in continuous scanning. In general, no overlaps occur in range image, and no registration is needed. The city range image is acquired by aligning the scanner's scan planes successively along the vehicle's moving direction. Previous research is mainly about how to obtain a façade model of the buildings [4, 7, 11]. In this paper, we manage to link the obtained façade model of one building with its information saved in a 2D digital map.

2-3 Range Image Segmentation

Range image segmentation is used in our analysis to locate the boundary lines of buildings in the city range image. Range image segmentation methods can be classified into two categories: region based methods [10] and edge based methods [13]. Region based methods group pixels into regions according to homogeneity measures. They suffer the problem of complex control and difficulty in implementation. On the other hand, edge based methods, which locate the boundaries of the regions by edge detection, suffer the problem of unconnected boundaries. However, edge based segmentation is adopted in our research because of its simplicity.

The edge model used in our analysis is proposed in [13]. It is illustrated in figure 1. For a pixel at position x_0, the depth values on the left and the right sides of x_0 are modeled by local line equation f_1 and f_2 respectively. If $f_1(x_0)$ is not equal to $f_2(x_0)$, that is, if h is greater than 0, there exists a step edge at x_0. If $f_1(x_0)$ is equal to $f_2(x_0)$, and k_1 is not equal to k_2, there exists a crease edge at x0. If $f_1(x_0)$ is equal to $f_2(x_0)$, and k_1 is equal to k_2, there is no edge at x_0. Basically, our method detects step edges using a certain threshold value.

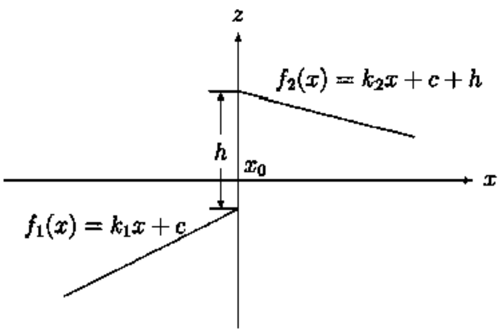

Figure 1 Range image edge model [13]

3. City Range Image Analysis

The overall flow of our city range image analysis is illustrated in figure 2. For a given city range image, range data of all buildings are extracted by removing obstacles using a histogram. Then the buildings' range data are segmented, and a pattern of the city range image is generated from this segmented image. Finally, the range image's pattern is matched with the pattern of a digital map using a pattern matching algorithm based on dynamic programming. Each step is described in detail in the following subsections.

3-1 Removing Obstacles

A city range image is captured by a line scan laser scanner when a data acquisition vehicle moves on the road. The objects between laser scanner and the buildings, such as trees, cars, and electrical posts, are recorded in the range image. These obstacles should be removed from the range image.

If the buildings are not transparent, the obstacles in the range image must be between the laser scanner and the buildings. In our experiments, the data acquisition vehicle tried to move in a line parallel to the road, so that the distance value between the building façades and the laser scanner remains almost the same. If the range image is divided by a vertical plane between the building facades and the obstacles, the range image can be divided into a range image of buildings and a range image of obstacles.

An illustration of removing obstacles using a histogram is shown in figure 3. The horizontal axis shows the distance value from the scanner, and the vertical axis shows the number of points at a distance. The horizontal coordinate value (about 14) corresponding to the maximum vertical coordinate value (about 11000) is the distance value of the building façade points. If the range image is divided by a vertical plane shown as a vertical line in figure 3, the right becomes a range image of the buildings, and the left becomes a range image of the obstacles.

3-2 Edge Detection Based Segmentation

Because only vertical boundary lines can be determined from the 2D digital map, the vertical boundary lines of the buildings in a city range image are necessary in matching the city range image and the digital map. Because of existence of interval between two adjacent buildings and big distance difference between two parallel planes of one building, the vertical boundary lines of the buildings become vertical step edges in the city range image. The edge based segmentation method is used in our analysis to locate vertical edges in the city range image.

After evaluating various edge detectors, we prefer the output result of the Canny edge detector. There are a lot of edges made from windows or doors, and these edges are weak compared with edges from the boundary lines of buildings. Some of these weak edges can be erased by adjusting the threshold of the Canny edge detector.

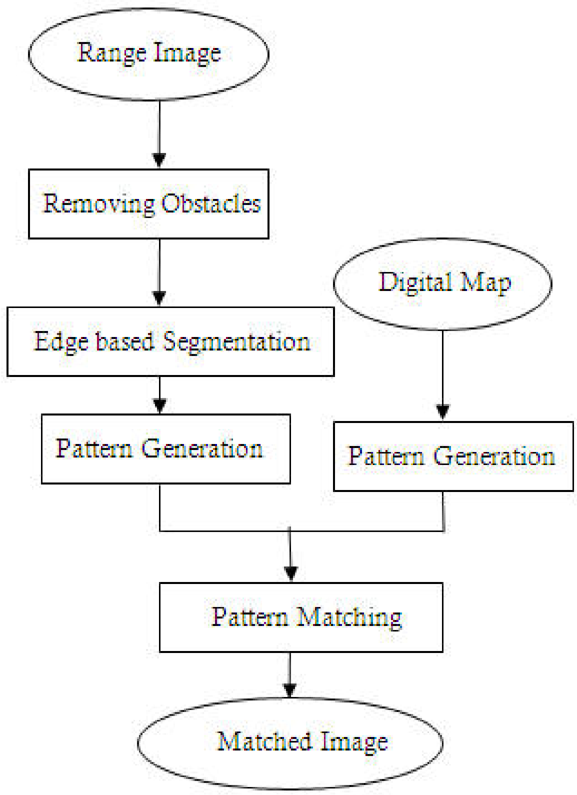

Figure 2 Analysis flow

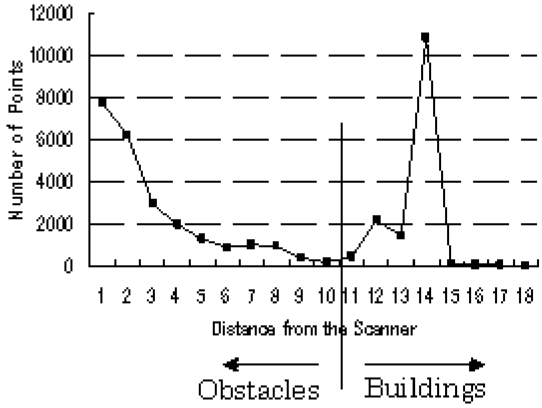

Figure 3 Removing obstacles using a histogram

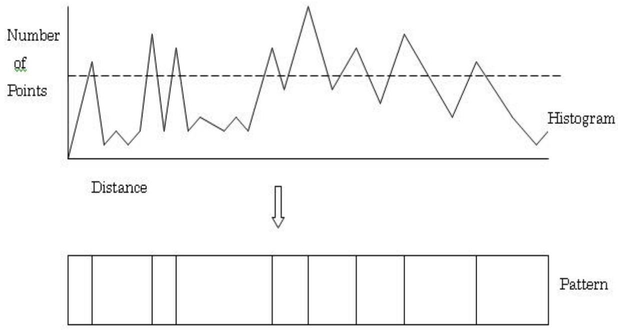

Figure 4 Pattern generation from a city range image's edge map

3-3 Pattern Generation

As stated in the previous subsection, we assume all vertical boundary lines of buildings can be captured and can be represented as vertical edges in city range image. Because of noise and error, there are often more vertical edges generated in the previous step than the edges generated by the boundary lines of buildings. And not all boundary lines can be identified directly. We made a histogram of the city range image's edge map generated in the previous step along the direction of the data acquisition vehicle's movement, and then generated one pattern line from one local maximum value greater than a given threshold in this histogram as illustrated in figure 4.

Pattern lines of an existing 2D digital map are generated by making a projection from visible corner points of buildings on the data acquisition vehicle's moving path. One projection point means one pattern line. This is illustrated in figure 5. The white arrow shows the data acquisition vehicle's moving direction. The black arrow shows the building corner's projection direction.

3-4 Pattern Matching Based on Dynamic Programming

Some matching algorithms based on dynamic programming were used to match video image with 2D digital map in previous research. [9, 12] A pattern matching algorithm based on dynamic programming is used in our research for matching the patterns of a city range image and that of a digital map. Thus correspondence between buildings in the city range image and that in the digital map can be determined. At the same time, error accumulation in city range data can be minimized.

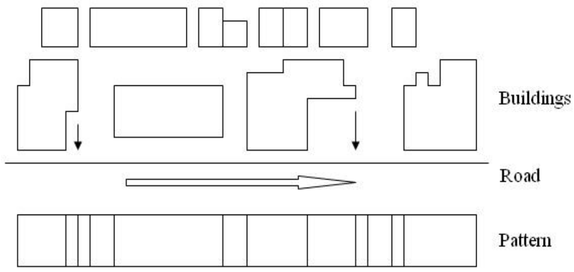

Figure 5 Pattern generation from a digital map

The pattern of the digital map is defined as:

$P_M = \{P_{M1}, P_{M2}, P_{M3}, \dots, P_{Mm}\}$.

And the pattern of the city range image is defined as:

$P_N = \{P_{N1}, P_{N2}, P_{N3}, \dots, P_{Nn}\}$

The value of P_{Mi} $(1 \le i \le m)$ and P_{Nj} $(1 \le j \le n)$ is the distance value between the start point and the pattern lines along the data acquisition vehicle's moving path. In order to simplify the problem, P_{M1} and P_{N1} are defined as 0. The length of the data acquisition vehicle's moving path in range image is changed to the length of the moving path in the digital map, that is, $P_{Mm} = P_{Nn}$.

In order to improve the matching result, we consider data existence attributes, on which side of one pattern line data exist. We can define $f_M = \{f_{M1}, f_{M2}, f_{M3}, \dots, f_{Mm}\}$ for P_M ; the value of f_{Mi} $(1 \le i \le m)$ is:

$$f_{Mi} = \begin{cases} L & \text{if building data exists only on left side} \\ R & \text{if building data exists only on right side} \\ B & \text{if building data exists on both sides} \end{cases}$$

$f_N = \{ f_{N1}, f_{N2}, f_{N3}, \ldots, f_{Nn} \}$ for P_N can be defined in the same way.

The cost $C[i, j]$ $(1 \le i \le m, 1 \le j \le n)$ of matching P_{Mi} and P_{Nj} is defined as the following:

$$C[1,1] = 0$$

$$C[i,1] = C[i-1,1] + (P_{Mi} - P_{M,i-1}) \times (1 + R \times F(f_{Mi}, f_{M,i-1}))$$

$$C[1, j] = C[1, j-1] + (P_{Nj} - P_{N,j-1}) \times (1 + R \times F(f_{Ni}, f_{N,i-1}))$$

$$\begin{aligned} C[i, j] = \; & \min\{C[i, j-1] + (P_{Nj} - P_{N,j-1}) \times (1 + R \times F(f_{Nj}, f_{N,i-1})), \\ & C[i-1, j] + (P_{Mi} - P_{M,i-1}) \times (1 + R \times F(f_{Mi}, f_{M,i-1})), \\ & C[i-1, j-1] + \sqrt{(P_{Mi} - P_{M,i-1})^2 + (P_{Nj} - P_{N,j-1})^2} \\ & \times (1 + R \times F(f_{Nj}, f_{Mi}))\} \end{aligned}$$

R means excessive cost for matching two pattern lines whose data are on different sides.

$F(a,b)$ is defined as:

$$F(a,b) = \begin{cases} 0 & if \;\; a = B \; or \; b = B \\ 0 & if \;\; a != B \; and \; b != B \; and \; a = b \\ 1 & if \;\; a != B \; and \; b != B \; and \; a != b \end{cases}$$

4. Experiments

We acquired range images of some streets near Institute of Industrial Science, University of Tokyo, using SICK LMS200 laser scanners mounted on the top of a data acquisition vehicle. These scanners operated at a frequency of 75 Hz during our experiment.

During our experiment, we tried to make the vehicle run in a line parallel to the direction of the road at a constant speed less than 30 kmph. The scanner scanned buildings perpendicular to the vehicle's moving direction when the vehicle moved on the road.

In our analysis, the part of the range image lower than 3 meters was removed to reduce the impact of obstacles, such as trees and cars. In fact, all buildings along the street are higher than 3 meters, so this did not affect the analysis result.

The matching result between a city range image of Uehara2-29, Shibuya-Ku, Tokyo and a digital map is shown in figure 6. The vertical line segments in the upper and the lower part represent the pattern lines generated from the range image and that from the digital map respectively. Every building is marked using its left and right pattern lines.Two matched pattern lines are connected by the line segments in the middle part. Some reasons for existence of unmatched pattern lines are change of the data acquisition vehicle's speed and direction, noise such as electric posts, and measurement error.

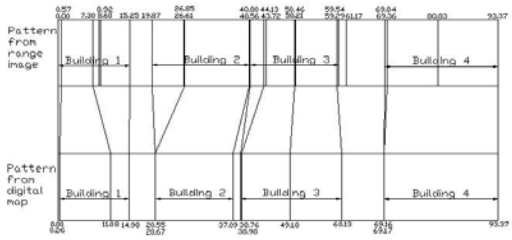

Figure 6 Matching result of a block

5. Conclusion

In this paper, a method of matching a city range image with a digital map is introduced. After removing obstacles and edge based segmentation, the city range image is mapped with the 2D digital map using a pattern matching algorithm based on dynamic programming. The correspondence of a single building in the digital map with its range image becomes available. More information about the range image can be obtained from the digital map, and a more precise geometrical model of the building's façade can be obtained from its range image.

One contribution of this research is matching between a city range image and a digital map. Because of change in speed and direction of the data acquisition vehicle, the distance between pattern lines changes. Pattern matching based on dynamic programming has been shown to be able to work well under this condition.

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