3D Modeling and Refinement of Residential Maps Using Range Scanners

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Abstract This paper introduces a method of making 3D models of buildings in a 2D residential digital map, and refining the building data in the digital map. The range image of the streets acquired by line scan laser scanners that moves in the streets is used. The pattern lines of the range image are determined using edge detection or depth analysis. Then these pattern lines are matched with pattern lines of the digital map using a pattern matching algorithm based on dynamic programming. Thus the buildings in digital map and their range images are linked together. The 3D model of the buildings can be constructed from their corresponding range images.

Keyword: Range Image, Digital Map, Edge Detection, Pattern Matching, Dynamic Programming

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1. Introduction

In recent years, the demand for 3D models of the real world has increased rapidly, because 3D models are very useful in many fields [1]. The existing 2D residential map of urban areas has contained precise geographical information. In this paper, we focus on 3D modeling of existing buildings in urban areas using an existing 2D digital map [2]. The cost of 3D modeling can be reduced by utilizing geographical information in the digital map. And at the same time, the existing digital map can be refined.

Although the precise height and rooftop shape of buildings can be determined by airborne images [3, 4, 5], the precise geometrical representation of building facades in city areas is still unavailable. So the building facades are our main concern. Now building facades in city areas are constructed from video images taken from the ground. Because range images are more precise in representing geometrical information than video image, range images taken from the ground are adopted in this paper. The range images of the streets, which contains buildings, electrical posts, trees, and others, are acquired by line scan laser scanners scanning buildings when running along the streets.

The acquired range image is matched with a 2D digital map using a pattern matching algorithm based on dynamic programming, so that the range image of a building's façade and the geographical information of that building in the digital map can be linked together. The range image of the building façade can be used to construct the 3D model of the building. This kind of building model is especially useful for pedestrians or drivers on the road. Because the range image is the current state of the buildings, the building data in the digital map can be refined using this range image.

The remainder of this paper is organized as follows. In section 2, city range image is briefly introduced. Analysis of city range image using edge detection is described in section 3. Analysis of city range image using depth analysis is described in section 4. Our experiments are described in section 5. The last section is the conclusion of this paper.

2. City Range Image

A city range image is a range image of streets in a city area, in which there exist buildings, trees, cars, electrical posts, and pedestrians. There exist some previous researches about city range image, such as [6, 7]. A survey about city range image acquisition and model generation can be found in [8]. Our main concern is the building façades. In order to acquire the building façades data in a wide area effectively, ground based continuous scanning is adopted. A line scan laser scanner mounted on a data acquisition vehicle scans the buildings when the vehicle moves on the road, and the city range image is acquired by aligning the scanner's scan planes successively.

3. City Range Image Analysis

The overall analysis flow is illustrated in Fig. 1. First, the obstacles in front of the buildings are removed from the city range image. Then the vertical edges are detected in the city range image, and pattern lines are generated from these vertical edges. Finally, these pattern lines are matched with the pattern lines of a digital map using a pattern matching algorithm based on dynamic programming. These steps are described in the following subsections. The emphasis is put on pattern matching based on dynamic programming.

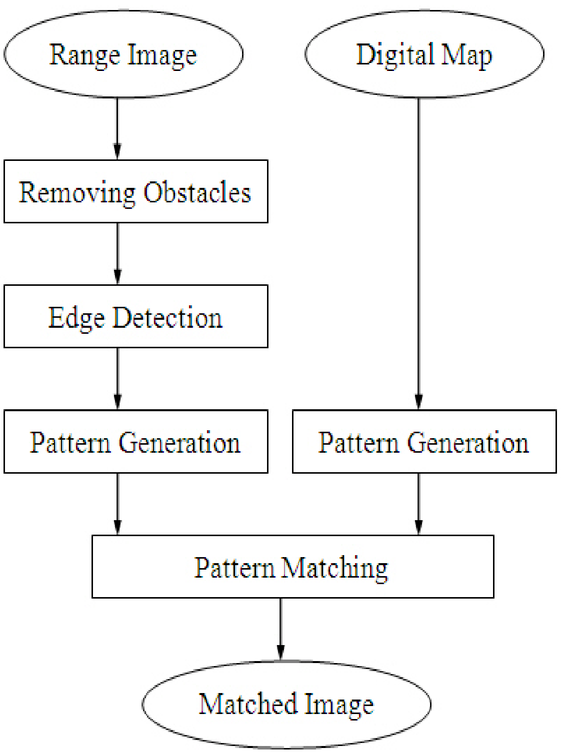

Figure 1 Overall analysis flow

3-1 Removing Obstacles

The obstacles are the objects in front of the buildings in the city range image, such as trees, cars, and pedestrian. These obstacles are removed from the range image to improve the performance of the following edge detection and to extract only building façade data.

If the laser scanner moves in a line parallel to the road, the distance between the building façades and the scanner remains almost the same. And the distance between the obstacles and the scanner must be smaller than that between the building façades and the scanner. The obstacles are removed by removing data points with distance values less than a value between the building facades' distance and the obstacles' distance.

3-2 Edge Detection

The vertical boundary lines of the buildings in the city range image are needed to be located to match with that in the digital map. Canny edge detector is used to locate vertical edges, which include the edges of the vertical boundary lines of the buildings. Canny edge detector can erase a lot of edges of windows or doors by adjusting its threshold value.

3-3 Pattern Generation from a City Range Image

There are often more vertical edges detected in the previous step than the vertical boundary lines of the buildings in the city range image. So a histogram of vertical edge points along the scanner's moving direction is made from vertical edge map of previous step, and pattern lines are generated from scan lines with local maximum values greater than a given threshold.

3-4 Pattern Generation from a Digital Map

Pattern lines of a 2D digital map are generated by making a projection from visible corner points of buildings on the scanner's moving path. One projection point is one pattern line.

3-5 Pattern Matching Based on Dynamic Programming

Pattern matching based on dynamic programming has been studied widely. Dynamic programming was used to match a video image with a 2D digital map in previous research [9, 10]. The dynamic programming is adopted to match a city range image with a 2D digital map in this paper.

By pattern matching based on dynamic programming, the vertical boundary lines of the buildings can be located in the vertical edges of the range image. At the same time, error accumulation in range data can be minimized.

The pattern of the digital map is defined as:

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

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, $P_{Mm} = P_{Nn}$. All P_{Nj} $(1 \le j < n)$ change with P_{Nn} in the same scale.

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:

$$
\begin{aligned}
&C[1,1] = 0\\
&C[i,1] = P_{Mi}\\
&C[1,j] = P_{Nj}\\
&C[i,j] = \min\{C[i, j-1] + (P_{Nj} - P_{N,j-1}),\\
&\qquad C[i-1, j] + (P_{Mi} - P_{M,i-1}),\\
&\qquad C[i-1, j-1] + \sqrt{(P_{Mi} - P_{M,i-1})^2 + (P_{Nj} - P_{N,j-1})^2}\}
\end{aligned}
$$

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:

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

$f_N = \{f_{N1}, f_{N2}, f_{N3}, \dots, f_{Nn}\}$ 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:

$$
\begin{aligned}
&C[1,1] = 0\\
&C[i,1] = C[i-1,1] + (P_{Mi} - P_{M,i-1}) \times (1 + R \times F(f_{Mi}, f_{M,i-1}))\\
&C[1,j] = C[1, j-1] + (P_{Nj} - P_{N,j-1}) \times (1 + R \times F(f_{Ni}, f_{N,i-1}))\\
&C[i,j] = \min\{C[i, j-1] + (P_{Nj} - P_{N,j-1}) \times (1 + R \times F(f_{Nj}, f_{N,i-1})),\\
&\qquad C[i-1, j] + (P_{Mi} - P_{M,i-1}) \times (1 + R \times F(f_{Mi}, f_{M,i-1})),\\
&\qquad C[i-1, j-1] + \sqrt{(P_{Mi} - P_{M,i-1})^2 + (P_{Nj} - P_{N,j-1})^2}\\
&\qquad \times (1 + R \times F(f_{Nj}, f_{Mi}))\}
\end{aligned}
$$

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

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

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

4. City Range Image Analysis Using Depth Analysis

The overall analysis flow using depth analysis is illustrated in Fig. 2. The removing obstacles and edge detection in the Fig. 1 are replaced by depth analysis. Depth analysis and its pattern generation are introduced in this section.

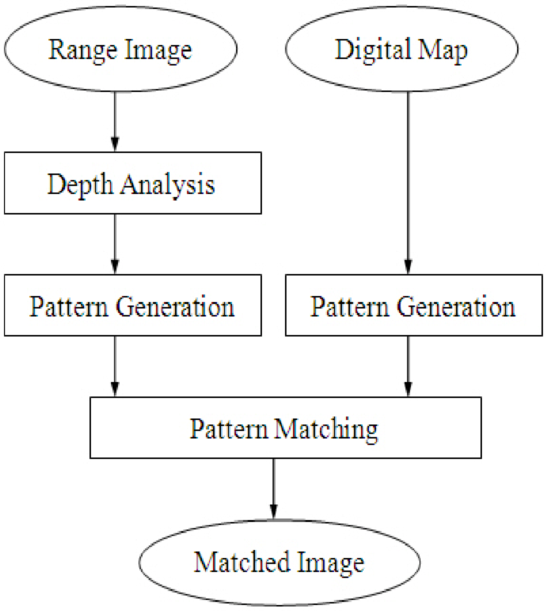

Figure 2 Overall analysis flow using depth analysis

4-1 Depth Analysis

The basic idea of depth analysis is to locate vertical boundary lines of the buildings in a city range image through considering depth in space areas between adjacent buildings.

If the laser scanner moves in a line parallel to the road, the distance value between the building façades and the scanner remains almost the same. If there is no object with a distance value less than that of the adjacent two building façades, the distance value in the space areas should be 0 or much larger than that of two adjacent building façades. 0 means that there is no object in the space area. A larger distance value means that there are some objects farther than the adjacent building façades.

If the line type laser scanners scan buildings vertically, one scan line should be in the building areas or in the space areas. Most of non-ground points of scan lines in building areas are points on the building façade or points on some objects in front of the building façade. On the other hand, most of non-ground points of scan lines in space areas are points on some objects farther than the building façade.

The distance of a scan line can be represented as the median value of the depth values of all of non-ground points of this scan line. For a building façade parallel to the scanner's moving direction, there should be some continuous scan lines with an almost equal median values. For a building façade not parallel to the scanner's moving direction, there should be some continuous scan lines with an almost equal change speed of median values. If there is an obstacle, such as a tree or an electrical post, in front of a building facade, there should be a few continuous scan lines with relatively small median value. If the left building area and the right building area of the obstacle are with the same depth value, these two areas are connected into one building area. On the other hand, in space areas, there are a number of scan lines with a zero median value or big median values that changed quickly. The reason for this fast change is that points of a scan line in space areas are often points on different objects with different depth values. So variance of depth values of scan lines in space areas is often large than that in building areas.

An illustration is shown in Fig. 3. The horizontal axis shows scan line number, and the vertical axis shows median depth values of scan lines. The left and right continuous scan lines with almost equal depth values are in two building areas respectively. The scan lines with depth values much greater than that of both building areas are in the space area. There are a few continuous scan lines in the left building area with depth values less than that of the left building area, so there is possibly a tree or electrical post in front of the left building.

4-2 Pattern Generation Using Depth Analysis

Scan lines in space areas and building areas in a city range image can be determined using the median values of scan lines. Instead of the leftmost and rightmost scan lines of building areas, the rightmost and leftmost scan lines of space areas are used to generate pattern lines of the buildings. Because no pattern line for the middle vertical line of the L-shape building is generated by using scan lines in space areas.

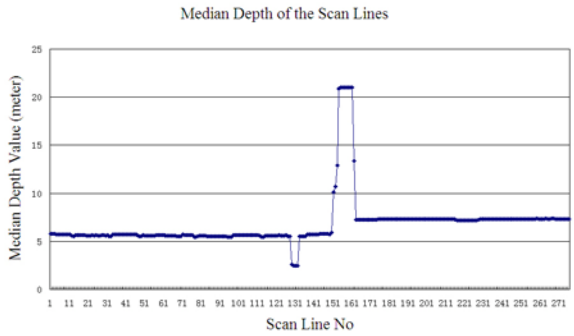

Figure 3 Example of median depth values of scan lines

5. Experiment

We acquired range images of some streets using SICK LMS200 scanners. These scanners operated at a frequency of 75 Hz during our experiments. The scanners were mounted on the top of a data acquisition vehicle. During our experiments, 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 streets are higher than 3 meters, so this will not affect the analysis result.

The matching result between city range image and digital map of a plot are shown in Fig. 4 and Fig. 5. Fig. 5 is the matching result with data existence attributes, that is, considering which side of a pattern line contains data. And Fig. 4 is the result without data existence attributes.

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 line segments in the middle part. Some reasons for the existence of unmatched pattern lines are change of the data acquisition vehicle's speed and direction, noise such as electric posts, and error. All four buildings are matched correctly in Fig. 5. Only building 1 is matched correctly in Fig. 4. This shows that data existence attribute makes pattern matching more effective and robust.

The median depth values of scan lines of another plot along the scanner's moving direction are shown in Fig. 6. The horizontal axis is scan line number, and the vertical axis is the median depth value of every scan line. The four areas around the four local maximum depth value, line 160, line 300, line 450, and line 610, are four spaces between the buildings. There are some electrical posts with less depth values in the building areas. All 5 buildings in this plot can be identified. The two buildings on the right are not parallel to the scanner's moving direction.

The variance of depth values of scan lines of the plot is shown in Fig. 7. The horizontal axis is scan line number, and the vertical axis is the variance of depth values of every scan line. The variance value in the building area is small, because most points of a scan line are on the same vertical building façade. On the other hand, the variance value in the space area is big, because the points can be on different objects with different depth values.

6. Conclusion

In this paper, matching a city range image with a digital map using a pattern matching algorithm based on dynamic programming is introduced. The pattern lines of the city range image are determined using edge detection or depth values of scan lines. Pattern matching based on dynamic programming has been shown to be able to work well. The matched range images of the buildings can be used to generate 3D model of the buildings, and refine the building data in the digital map. In the future, edge detection and depth analysis will be considered together to further improve the overall performance.

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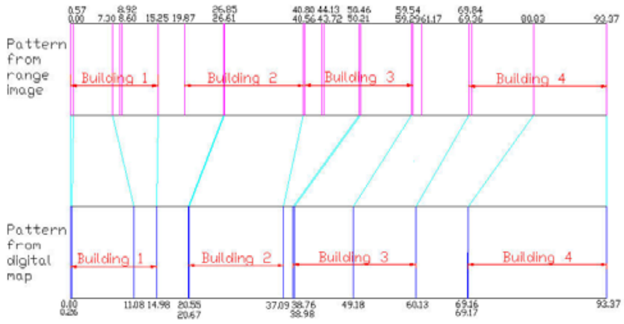

Figure 4 Matching result without data existence attributes

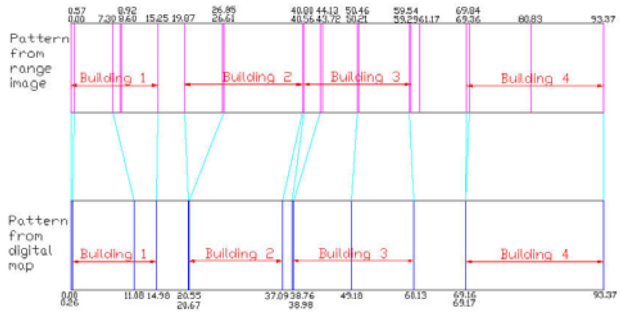

Figure 5 Matching result with data existence attributes

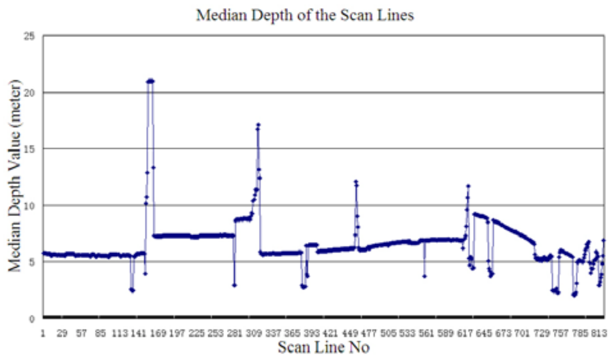

Figure 6 Median depth values of the scan lines

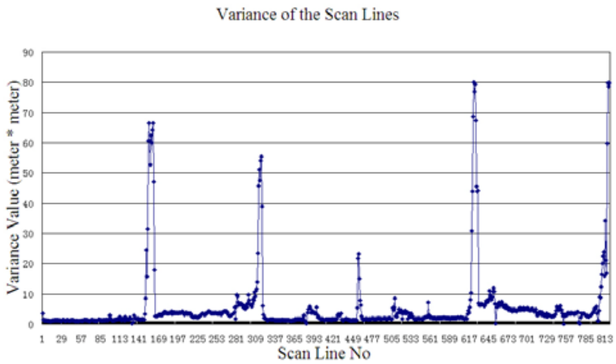

Figure 7 Variance values of the scan lines

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