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Matching Range Images of Streets with a Residential Map

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Abstract

In order to realize 3D modeling and refinement of buildings in a digital 2D residential map using range images of the streets, we match range images of streets with the digital map. After pattern lines of the range images are determined using edge detection and depth analysis, they are matched with pattern lines of the digital map using a pattern matching algorithm based on dynamic programming. The range images of every building can be extracted and linked with the corresponding building data in the residential map according to the matching result. 3D modeling and refinement of the buildings in the 2D residential digital map can be realized using their range images.

1. Introduction

Because 3D models are very useful in many fields [1], the demand for 3D maps of the real world has increased. But the cost of making 3D map is very high. The existing 2D residential maps of urban areas contain precise geographical information. [2] It can reduce effectively the cost of making 3D map by 3D modeling of existing 2D residential maps.

A main problem in 3D modeling of a 2D map is the unavailability of the buildings' facade information. So we use range images to acquire the geometrical information of the building facades. We extract range images of building façades and link them to the corresponding building data in the 2D digital map. Thus the geometrical information of the building façades becomes available, and 3D modeling and refinement of the buildings in the digital map can be realized.

In order to acquire the range images of the streets, the laser scanners can be mounted on planes [3, 4, 5] or vehicles [6,7]. Because the lower part of the buildings in the urban areas is often hidden by other buildings and become invisible for the laser scanners on planes, the laser scanners are mounted on vehicles in our research. In order to acquire range images in a wide area quickly, the scanners scan the buildings when the vehicle moves on the road. Because high scan speed is necessary, line scan type laser scanner is used.

The remainder of this paper is organized as follows. Our method of matching a range image of streets with a digital map is described in section 2. Verification of the matching result is described in section 3. Experiments are described in section 4. And the section 5 is the conclusion of this paper.

2. Matching Range Images of Streets with a Digital Map

A range image of a street contains buildings and something else, such as trees, cars, electrical posts, and pedestrians. An example of a range image of streets is shown in figure 1. The image was taken by a line scan type laser scanner mounted on a vehicle. The laser scanner scanned buildings vertically when the vehicle moved on the road in front of the buildings.

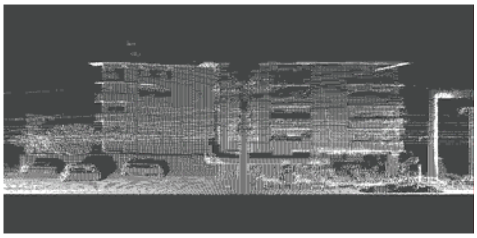

Figure 1. Example of a rang image of streets

We extract the range ranges of the building facades and link them with the digital map by matching the range image with the digital map. The overall flow is illustrated in figure 2. First, the objects, such as trees, cars or electrical posts, in front of the buildings are removed from the range image. Then edge detection is used to detect vertical edges from the remained range image. Depth analysis is used to locate the boundary lines of the spaces between the buildings from the original range image. The location of visible vertical boundary lines of the buildings along the road is determined in pattern generation of the residential map. The depth analysis result, the location of the visible boundary lines in the residential map, and the vertical edges from edge detector are used together to generate pattern lines of the range image. Finally, these pattern lines are matched with the pattern lines of the residential map using a pattern matching algorithm based on dynamic programming. These steps are described in the following subsections.

2-1 Removing Obstacles

The obstacles are the objects, such as trees, cars, and pedestrian, in front of the buildings in the range image. Our objective is 3D modeling and refinement of the buildings in the residential map, so only the range data of the building façades are needed. These obstacles are removed first.

If the data acquisition vehicle moves in a line parallel to the buildings, the horizontal distance D_b between the building façades and the scanner remains almost the same.

Because the obstacles are in front of the buildings in the range image, the horizontal distance D_o between the obstacles and the laser scanner is less than D_b. The obstacles' data points can be removed by removing all points with a horizontal distance value less than a threshold value D_p that is in the range (D_o, D_b), i.e. $D_p \in (D_o, D_b)$. Because depth value is recorded directly in the range image, it is easy to remove obstacles using the horizontal distance of points.

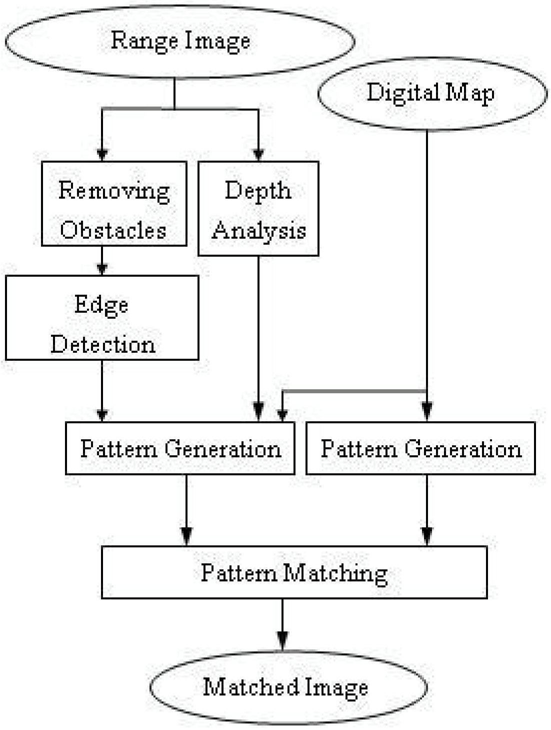

Figure 2. Overall analysis flow

2-2 Edge Detection

In order to make 3D model of a building, the range image of the building is needed to be extracted from the range image of the street. If the two vertical boundary lines of the building are located in the range image of the street, the range image of the building is the non-ground range data between its two vertical boundary lines. There is building data on one side of a vertical boundary line, and there is no building data on the other side of the vertical boundary line, so the vertical boundary line is a vertical edge in the range image. The vertical edges in a range image of streets include not only edges from the vertical boundary lines of the buildings but also edges from the obstacles or noise. Canny edge detector is used to find the vertical edges from the range images, because canny edge detector can erase some edges resulting from the obstacles or noise by adjusting its threshold value.

2-3 Depth Analysis

Because the buildings are vertical and our line type laser scanners scan buildings vertically, one scan line scans a building façade or an object in a space area between two buildings. In most cases, the objects in a space area are behind the space's adjacent two buildings, so the horizontal distance between the laser scanner and these objects are much larger than that between the laser scanner and the adjacent two building facades.

The median depth of a scan line is defined as the median of horizontal distance values between the laser scanner and all non-ground points on the scan line. The median depth value of scan lines in a space area is larger than that in its adjacent building façade areas. The building areas are some continuous scan lines with an almost equal median depth values or with an almost equal change speed of median depth values. The space areas are some scan lines with larger median values that often change quickly. A scan line corresponding to a vertical boundary line of the building can be located between the building area and one of its adjacent space areas. An illustration of depth analysis is given in figure 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 larger than that of both building areas are in the space area.

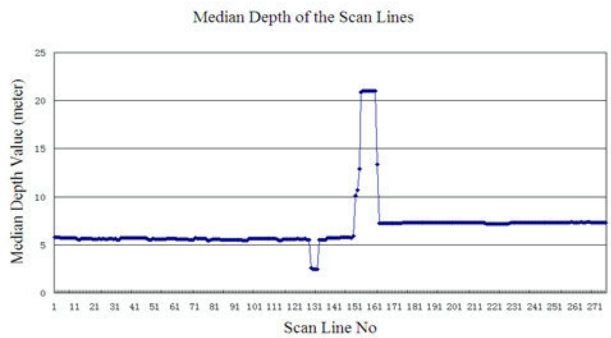

Figure 3. Depth analysis.

2-4 Pattern Generation from the Residential Map

Pattern lines of the 2D residential map are generated by making projection from visible corner points of buildings on the scanner's moving path. One projection point means one pattern line of the residential map. An illustration is shown in figure 4. The white arrow shows the scanner's moving direction. The black arrow shows the building corner's projection direction.

2-5 Pattern Generation from the Range Image

There are often much more vertical edges found in edge detection step than the actual number of vertical boundary lines of the buildings in a range image. If the number and length of the buildings in the range image and that in the digital map are almost the same, we can generate patterns only from vertical edges near the boundary lines found in depth analysis or near the pattern lines generated from the digital map. For example, the boundary lines found in depth analysis are represented by $BL_j \ (j = 1, \cdots, J)$, the pattern lines generated from the digital map are represented by $P_{Mi}\ (i=1,\cdots,I)$, and the given threshold value of distance change is D, only vertical edges in $[BL_j - D, BL_j + D]\ (j=1,\cdots,J)$ or in $[P_{Mi} - D, P_{Mi} + D]\ (i=1,\cdots,I)$ are remained.

Then a histogram of remained vertical edges along the scanner's moving direction is made, and pattern lines are generated from scan lines with local maximum number of vertical edge points larger than a given threshold. If there is no vertical edge near a boundary line found in depth analysis or a pattern line of the residential map, a pattern line of the range image is generated at the location of the boundary line or the pattern line of the residential map.

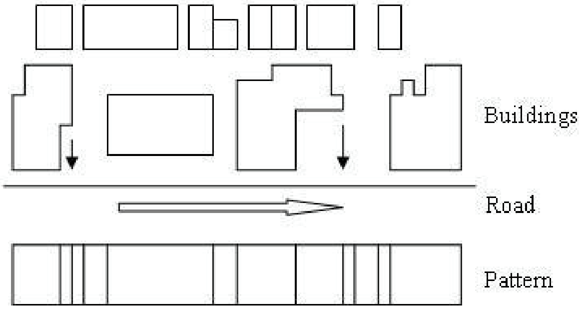

Figure 4. Pattern generation from the residential map

2-6 Pattern Matching Based on Dynamic Programming

A pattern matching algorithm based on dynamic programming is used to match the patterns generated from the range image with that from the digital map. The vertical boundary lines of the buildings in the range image can be located according to the matching result. The small error in the range image can be minimized by using dynamic programming.

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 range image is defined as:

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

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 in the range image and in the digital map respectively. In order to simplify the problem, P_{M1} and P_{N1} are defined as 0, and $P_{Mm} = P_{Nn}$.

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:

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

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

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

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

Building data are on the left or the right side of vertical boundary lines of the buildings. R_F is an excessive cost for matching two pattern lines whose data are on different sides. $F(\alpha,\beta)$ is defined as:

$$F(\alpha,\beta) = \begin{cases} 0 & ,\textit{data are on the same side of } \alpha \textit{ and } \beta \\ 1 & ,\textit{data are on different sides of } \alpha \textit{ and } \beta \end{cases}$$

The length of a block of buildings in the digital map and that in the range image are almost the same. So it is reasonable that a pattern line in the digital map should be matched to a pattern line in the range image with an approximately equal distance value. R_D is excessive cost for matching two pattern lines whose difference of distance is larger than a given threshold value. So $D(\alpha,\beta)$ is defined as

$$D(\alpha,\beta) = \begin{cases} 0 & ,|\alpha - \beta| \le Threshold \\ 1 & ,|\alpha - \beta| > Threshold \end{cases}$$

3. Verification

Because of the nature of dynamic programming, it is not guaranteed that the output of dynamic programming is the correct result. So it is necessary to verify the matching result. Now, three items are implemented in verification.

The first item is that building data should exist on the same side of P_{Mi} and P_{Nj} for matched digital map pattern P_{Mi} and range image pattern P_{Nj}. The second item is that distance between P_{Mi} and P_{Nj} should be not larger than the given threshold value, i.e. $|P_{Mi} - P_{Nj}| \le Threshold$.

If the building data exist on different sides of P_{Mi} and P_{Nj}, or the difference between P_{Mi} and P_{Nj} is larger than the given threshold value, i.e. $|P_{Mi} - P_{Nj}| > Threshold$, the matching result should be modified by searching another range image pattern for the digital map pattern P_{Mi}. Here, we explain the modification when $P_{Mi} > P_{Nj}$. The case of $P_{Mi} < P_{Nj}$ can be done in the similar way. If $|P_{Mi} - P_{Nj}| > Threshold$, try every range image pattern from $P_{Mi} - Threshold$ to P_{Mi} in the range of $[P_{Mi} - Threshold, P_{Mi}]$ until a range image pattern is found to meet the first and the second item. If $\left|P_{Mi} - P_{Nj}\right| < Threshold$, try every range image pattern from P_{Nj} to P_{Mi} in the range of $\left[P_{Nj}, P_{Mi}\right]$, and then from P_{Nj} to $P_{Mi} - Threshold$ in the range of $\left[P_{Mi} - Threshold, P_{Nj}\right]$ until a matched range image for P_{Mi} is found. If no range image pattern can be found, try every range image pattern from P_{Mi} to $P_{Mi} + Threshold$ in the range of $\left[P_{Mi}, P_{Mi} + Threshold\right]$. If no range image pattern can be found, the matching is treated as failed.

The third item is that height values of the buildings in the range image and the number of floors of the buildings in the digital map should change in the same direction. Because height values of different floors of different buildings may be different, height values in the range image are not in strict proportion to the number of the floors in the residential map. But it is reasonable to assume that a building with a more number of floors is higher than a building with a less number of floors.

4. Experiments

We have acquired some range images of streets using SICK LMS200 scanners mounted on a data acquisition vehicle that scan buildings perpendicular to the vehicle's moving direction at a frequency of 75 Hz when the vehicle moved on the road in a line at a constant speed. The residential map is "Zmap-TOWNII" [2] whose scale is 1:2500. The map is updated every 2 or 3 years.

The range images of some plots of buildings have been matched with the digital map. The matching result of a plot of four buildings with a total length of about 100 meters between a range image and the digital map are shown as an example in Figure 5. 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 a line segment 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. It is shown that all four buildings are matched correctly. The range image of a building façade is shown in figure 6.

5. Conclusion

In this paper, a method of matching a range image of streets with a digital map based on dynamic programming is described. The pattern lines of the range image are determined using edge detection, depth analysis, and pattern lines of the residential map. A pattern matching algorithm based on dynamic programming is used to match the pattern lines of the range image and that of the digital map. The boundary lines of the buildings in the range image are available from the matching result, and the range images of the building facades are linked to the buildings in the digital map at the same time. According to the experimental result, it is known that the method can work well. The range images of the building facades can be used to generate 3D model of the buildings in the 2D digital map, and to refine the building data in the digital map.

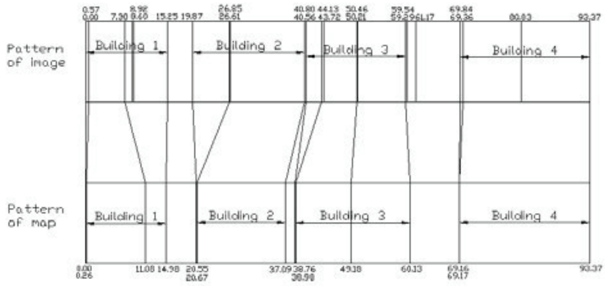

Figure 5. Example of matching result of four buildings

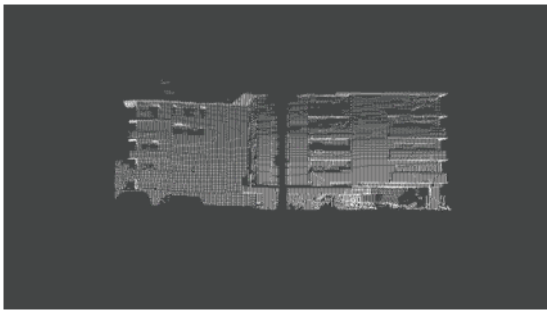

Figure 6. Example of range image of a building facade

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