3D City Modeling Using Laser Scan Data

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Abstract: This paper describes techniques for the automated creation of geometric 3D models of the urban area using two 2D laser scanners and aerial images. One of the laser scanners scans an environment horizontally and the other scans vertically. Horizontal scanner is used for position estimation and vertical scanner is used for building 3D model. Aerial image is used for registration with scan data. Those models can be used for virtual reality, tele-presence, digital cinematography, and urban planning applications. Results are shown with 3D point cloud in urban area.
Keywords: laser scanner, 3D modeling, position estimation, aerial images

1. Introduction

The recovery and representation of 3D geometric of the real world is one of the most challengeable problems in computer vision researches. With this work, we would like to address the need for highly realistic geometric models of the world, in particular to create models that represent outdoor urban environment. Those models can be used in applications such as virtual reality, tele-presence, digital cinematography and urban planning.

There are many approaches to create 3D city modeling. In remote sensing field, satellite or aerial images are used to create 3D models using stereo matching method. But their resolution is too low compared with laser scan data. So, they can't make detailed street scenes to be shown like walk-through.

Our goal is to create an accurate geometric representation of urban areas. The geometry of environment is acquired using range-sensing technique. We have developed a system, which produces geometric correct 3D models representing the environment. Our system is mounted on a car. We can acquire horizontal and vertical data synchronously during driving through city roads. Later, those data are processed offline. Fig. 1 shows our data acquisition system. Job flow can be summarized as follows. First, we execute scan matching algorithm with horizontal data for estimating relative position of car and we know where we have to decide the position of vertical data. But, because of small errors and mismatches, there can be existed accumulated errors in world coordinate. To correct them, we execute global position estimation with aerial images. This process correct our 3D modeling geometrically.

2. System constitution

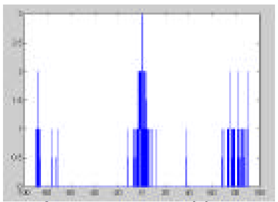
Fig. 1. Data acquisition system

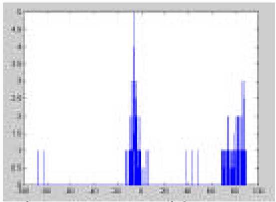
We use a car as our mobile-sensing platform. The system is consists of three parts: Sensor part, processing part, and power part. The sensor part is consists of two 2D laser scanners and a CCD camera (used for texture mapping later). The processing part is consists of 2.0Ghz processor PC and high speed serial interface card for RS422 data communication. The power part has two 12V DC battery and DC-AC converter to supply power to sensor and PC. Fig. 2 shows the sensor part. Horizontal scanner uses for estimating relative position of sensor and vertical scanner acquires the shape of the complete building facades while driving. Scanner can scan 180 degrees with 0.5 degrees' resolution and 30 times per second.

Fig. 2. Sensor part

3. Histogram correlation matching

We can get relative position of each scan data by scan-matching algorithm based on histogram correlation matching. First we assume world coordinate as [X, Y, q] and a car's local coordinate [x, y, f]. X,Y is ground plane and θ is direction angle. x is car's moving direction and y represents the direction of scanning. ϕ is heading angle of car. We assume that the X, Y plane is flat which means city roads are flat. In every horizontal scan data, the car's moving vector $\Delta x, \Delta y, \Delta \varphi$, displacements between scan data, is estimated with histogram correlation matching algorithm. The algorithm matches each scan by correlation of angle, x and y histograms. First, we compute angles between each point and make angle histogram of scan data pairs. And find maximum correlated angles $\Delta \varphi$. After we compensate each scan with estimated angle, we can find x and y displacement with x and y histograms. Fig. 3 shows example of finding angle displacement. By performing correlation (a) with (b). (c) is computed and we can find maximum correlated angle(pointed angle in (c), which is angle displacement between two scans. we can compute x, y displacement with the same manner. Fig. 4 shows the scan matching result.


a. reference scan's histogram


b. next scan's histogram

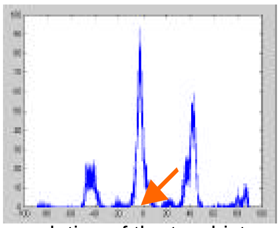
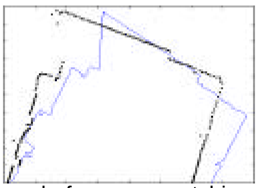

c. correlation of the two histogram

Fig. 3. Angle histogram correlation matching

Processing iteratively with every scan pairs, we can get car's world coordinate [X, Y, θ] by updating matching results as follows.

$$
\begin{aligned}
X_{k+1} &= X_k + \Delta x \cdot \cos(\theta_k + \Delta \phi) - \Delta y \cdot \sin(\theta_k + \Delta \phi) \\
Y_{k+1} &= Y_k + \Delta x \cdot \sin(\theta_k + \Delta \phi) + \Delta y \cdot \cos(\theta_k + \Delta \phi) \\
\theta_{k+1} &= \theta_k + \Delta \phi
\end{aligned} \quad (1)
$$


a. before scan matching

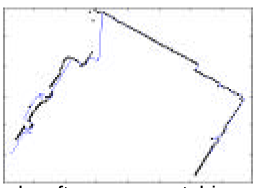

b. after scan matching

Fig. 4. Histogram correlation matching

Fig. 5 shows the area we build 3D model (Mangwon-dong, Seoul. 25centimeters resolution).

Fig. 5. Test area image and driving path (about 1km)

Although the estimation is quite accurate, accumulation of small errors can cause wrong path in world coordinate. Fig. 6 shows the z-image (position corrected horizontal scan data) resulted from histogram correlation matching. Because of accumulation errors, the path doesn't match to car's driving path. To correct these errors, global pose correction is necessary, which will be explained in next section.

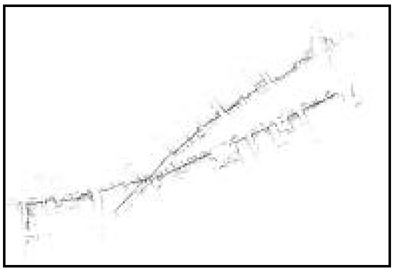


Fig. 6. Result image of histogram correlation matching

4. Registration with aerial images

As we mentioned above, to correct distortion of whole path, we have to register scan data to aerial images. By performing it, we can build correct geometric models of urban areas. We use Monte-carlo localization algorithm for our global localization problem. The algorithm represents car's k'th states with probability distribution $p(X_k, Y_k, \theta_k)$ and particles Pk, which is set of probability position samples of car. Monte-carlo localization is performed iteratively. In each step k, set of particles Pk is transformed to next step by following two phases. It is Prediction phase and update phase. In prediction phase, Pk is stated by scan matching vector with added noises. Because of noises, uncertainty of $p(X_k, Y_k, \theta_k)$ is increasing and particles Pk is diffused. In update phase, we compute correlation between k'th horizontal scan data of position Pk and aerial edge image along our driving path. Every correlation values operate as weight factor. Since correlation values represent how well the predicted position is matched to real position, particles with high weight value survive to next step k+1. By doing above process iteratively in each scan, we can get correct geometric world coordinate [X, Y, q]. Fig. 7 shows path corrected image with Monte-carlo localization algorithm.

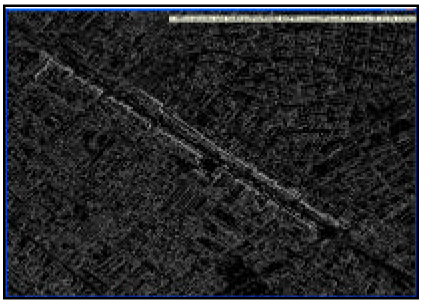


Fig. 7. Edge image with corrected path

4. Experimental results

Since displacements between movements are too small, we didn' t perform scan matching and Monte-carlo localization every scan but every fifteenth scan. Instead we use linear interpolation method between intervals of every fifteenth scan. With corresponding vertical scan data, we can get 3D models of urban area. Fig. 8 shows the 3D models of test area (Fig. 5.). We acquire scan data by driving city roads speed at 20 km per hour and it takes total 17,780 vertical scan data to build the model.

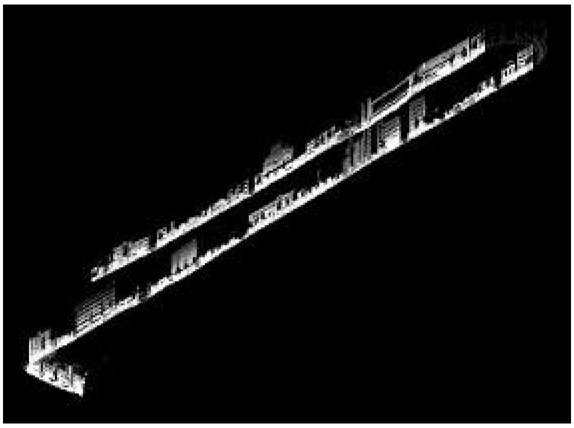


Fig. 8. Build 3D model

Also, Fig. 9 and Fig. 10 shows detailed views of tested area.

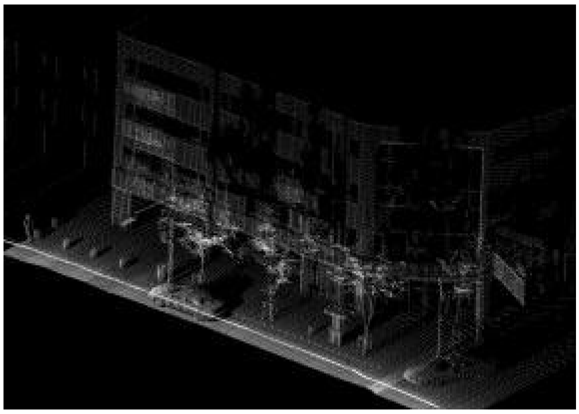


Fig. 9. Detailed view 1

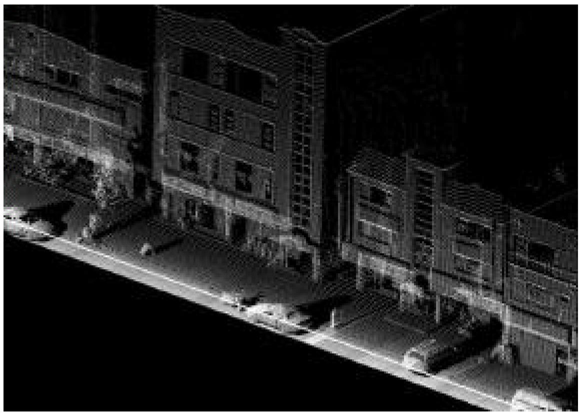


Fig. 10. Detailed view 2

5. Further work

So far, we build just 3D point cloud models. We will perform texture mapping on it using CCD camera images. And we will test with 1m resolution satellite images to register scan data. Also, fusing with DTM from the satellite images, we will realize 3D reality.

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