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Measurement and Construction of Road Surface Elevation Information based on Kriging model

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Abstract. In order to study the road digital elevation information of the front road surface, a method in this paper is proposed to measure the road surface model based on kriging model. Firstly, laser lidar is used to obtain the point cloud information of the road ahead of the vehicle. Secondly, extracting the road surface elevation information ahead of the vehicle and combining the point cloud information with the real-time position of the vehicle. Finally, the elevation information of the road surface was simulated by the Kriging agent model. The Kriging model was verified by experiments.

1. Introduction

Road detection is a key issue in any driver assistance system [1]. Laser scanning and lidar can be used to extract road conditions. The extraction of road conditions directly determines the driving performance of the vehicle. Therefore, it is very important to study the road elevation information.

The vehicle's identification of the elevation information of the road ahead mainly relies on the sensors, such as lidar, camera, inertial navigation system and global positioning system etc., to sense the motion state of the vehicle and the road information ahead. And the multi-sensor information fusion technology is used to extract the elevation information of the road in front of the vehicle. The construction of the front road surface is completed by processing the point cloud library. Using a depth camera, the 3D model is projected into a 2D plane [2-3] to capture the elevation information of the road surface. However, the position and orientation of the camera are constantly affected by the following factors: road defects or artifacts (such as rugged roads, speed buffers), car acceleration, uphill/downhill driving [4], these factors affect the accuracy of road detection. In addition, lidar technology has become a standard remote sensing technology for obtaining accurate topographic data over a large area [5-6].

In this paper, laser lidar technology is used to acquire 3D point cloud data, and establish a Kriging agent model, simulate road elevation information. In the end, the model of measurement road elevation information is verified by experimental methods.

2. Fusion and segmentation of point cloud data

The point cloud data is collected through the *ros_rslidar* package of the lidar and then obtain the real-time pose of the vehicle coordinate system in the *odom* coordinate system through the data fusion



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between the encoder and the inertial navigation system, and release the real-time pose of the lidar coordinate system in the *odom* coordinate system by transforming the pose of the model. The data which fuse the point cloud data and the real-time pose of lidar is the 3D point cloud of the road surface. The fused point cloud data is shown in Fig. 1. Since the amount of data is too large, the number of data points is more than 300. In the figure, only 35 data points are combined, and the number of point clouds is 1,128,960. Fig.2 is the experimental site.

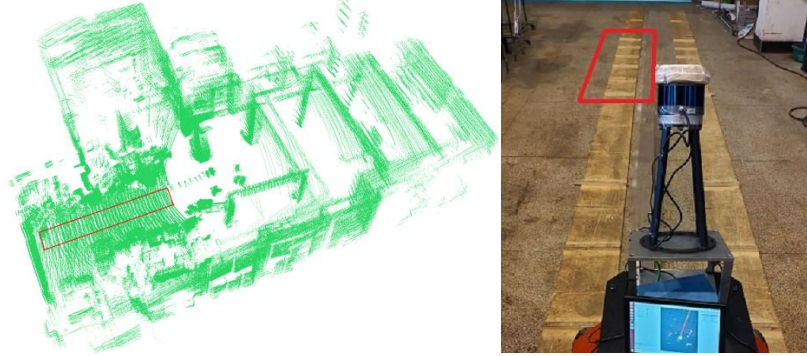


Figure.1. Fused point cloud data Figure. 2. Experimental site

Point cloud segmentation is usually done after the point cloud completes filtering and reducing samples. Since the point cloud segmentation of the system is only used to extract the point cloud of the relevant road surface in the front, the point cloud segmentation is performed first, and the general region is divided as shown in the red box in Fig. 3 (a). The principle of point cloud segmentation in this system is that the car body coordinate system is the reference coordinate system of the point cloud. The main problem is to set the width and height threshold. The height threshold only needs to be set to $\pm 0.3\text{m}$ of the approximate height of the road surface. The system sets the width threshold to $\pm 1.6\text{m}$ according to the actual width of the vehicle, which are the coordinates $(-0.8\text{m} < y < 0.8\text{m})$ of the point cloud in the car body coordinate system. The point cloud after segmentation is shown in Fig.3 (b).

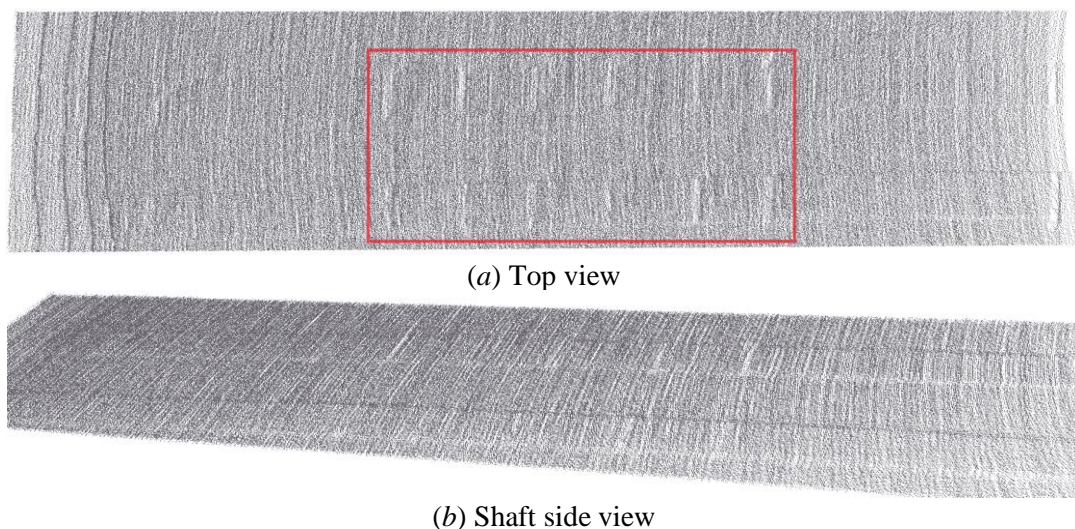


Figure 3. Point clouds after segmentation

3. Establishment the Kriging model

Pre-processing of the point clouds eliminates outliers and noise points. In order to obtain accurate digital elevation model (DEM) of the front road surface, these points and unobserved points are interpolated. The kriging model can better reflect the changes of various terrains, and can also predict

the response value of unobserved points based on all observed points. Therefore, kriging model is used to establish the DEM of the road surface, and the sampling points in the relevant range of the space are used to estimate the attribute values of the points to be inserted, and the accuracy of the road surface recognition can also be verified. The kriging model is established by the following steps. The one-dimensional analog response is globally estimated by a known polynomial and a stochastic deviation polynomial:

$$y(x) = f(x) + Z(x) \quad (1)$$

Where, the remainder $Z(x)$ is considered to be independent and identically distributed, such as normal distribution. For the kriging model, it can be expressed as:

$$y(x) = \sum_{j=1}^k \beta_j f_j(x) + Z(x) \quad (2)$$

Where $f_j(x)$ is the j -th known regression function. In general, $f_j(x)$ can be taken as a fixed constant, which does not affect the accuracy of the simulation. β_j is the correlation coefficient, expressed as a vector:

$$f(x) = [f_1(x), f_2(x), \dots, f_k(x)]^T \quad (3)$$

$$\beta = [\beta_1, \beta_2, \dots, \beta_k]^T \quad (4)$$

$Z(x)$ is considered to be a stochastic process, expressed as:

$$\begin{cases} \text{Cov}(Z(x^i), Z(x^j)) = \sigma^2 R \\ E(Z(x)) = 0 \end{cases} \quad (5)$$

Where R can be expressed by:

$$R = [R(x^i, x^j)]_{n \times n} \quad (6)$$

Where, R is a diagonally symmetric correlation matrix $n \times n$, and $R(x^i, x^j)$ is a correlation function between any two observation points x^i and x^j of the diagonal element. The related function $R(x^i, x^j)$ is:

$$R(x^i, x^j) = \exp \left[- \sum_{n=1}^N \theta_n |x_n^i - x_n^j|^2 \right] \quad (7)$$

Where θ_n is an unknown correlation parameter, and x_n^i and x_n^j are the n -th component of the observation points x^i and x^j , respectively. Then at the unknown point x^* , the best linear unbiased estimation $\hat{y}(x^*)$ is:

$$\hat{y}(x^*) = \hat{\beta} + r^T(x^*) R^{-1} (y - p \hat{\beta}) \quad (8)$$

$$\hat{\beta} = (p^T R^{-1} p)^{-1} p^T R^{-1} y \quad (9)$$

$$r^T(x^*) = [R(x^*, x^1), R(x^*, x^2), \dots, R(x^*, x^{n_0})] \quad (10)$$

Where n_0 contains the response value of each observation point, y is the column vector of vector n_0 , and p is a column vector containing the n_0 component.

The variance estimate $\hat{\sigma}^2$ is:

$$\hat{\sigma}^2 = (y - p \hat{\beta})^T R^{-1} (y - p \hat{\beta}) / n_0 \quad (11)$$

The kriging model is used to predict the mean square error s^2 at the unknown point x^* :

$$s^2(x^*) = \hat{\sigma}^2 \left(1 - r^T R^{-1} r + \frac{(1 - p^T R^{-1} r)^2}{p^T R^{-1} p} \right) \quad (12)$$

4. Experimental results and analysis

As shown in Fig. 4, it is the 3D model of the road surface in the red frame of Fig. 3 (a) obtained by Kriging model. The red part corresponds to the six protrusions of the road surface in the area, and the fluctuation of the road surface can be distinguished from the model. However, the overall pavement DEM model is not effective. There are two main sources of error: the perceptual error of the pose information and the measurement error of the lidar sensor. The typical accuracy of the lidar's ranging accuracy is $\pm 2\text{cm}$, and the DEM information transformation is less than 2cm , so it cannot be accurately identified, and only the convex part of the road surface can be judged.

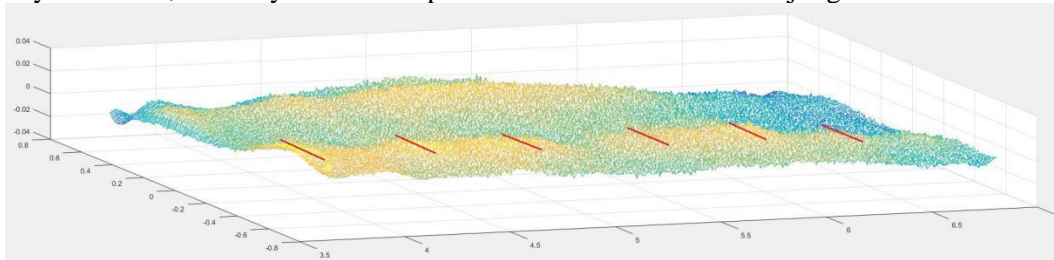


Figure 4.3D model of road surface

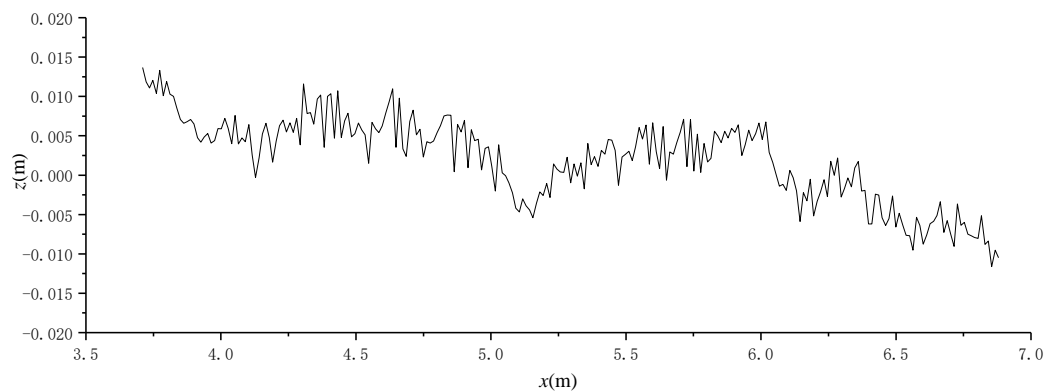


Figure 5. Two-dimensional road surface model

In order to analysis the error of the kriging model, the curve of the intersection of the kriging model and the $y = -0.45\text{m}$ plane is extracted, and the obtained 2D road surface elevation model is shown in Fig.5. It can be seen from the figure that the elevation range of the road surface is between -1cm and 1.5cm , and the typical accuracy of the lidar's ranging accuracy is $\pm 2\text{cm}$, so the accurate identification of the constructed road surface cannot be completed, and only the general trend can be seen. In order to further verify the recognition effect of the system, it is necessary to build a road surface with a larger elevation range for identification. The identified road surface is shown in Fig. 6.



Fig.6 The road surface

The road surface is identified by the above system, and the point clouds of the identified road surface are shown in Fig.7. Due to the sudden change of the road surface and the block on the rear road surface, which is shown in the red frame in Fig. 7 (a), linear interpolation is performed on the filtered point clouds. The default part of the road surface is linearly interpolated to obtain the default part of the road elevation information by extracting the elevation of the left and right points. The filled point clouds are shown in Fig. 7 (b).

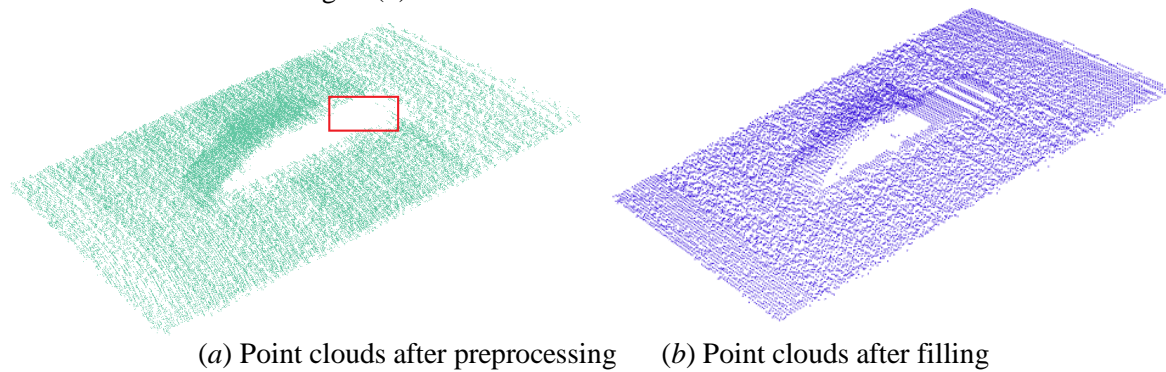


Figure 7. Road surface point clouds map

The error of obtained road surface elevation information measurement is shown in Fig.7.

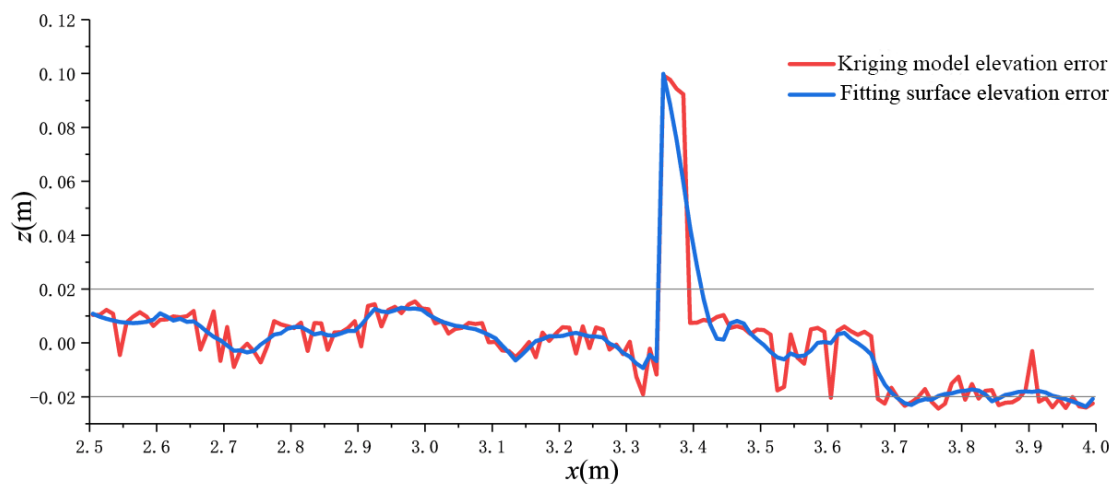


Figure 8. The error of road surface elevation information measurement

It can be seen from Fig.8. that the exception for the range of $3.35 < x < 3.45$, it is the missing partial path clouds in the red frame in Fig. 6 (a) because of the block of the lidar by the constructed road surface, so the part of the road is not reconstructed accurately, which result in larger errors. The rest of the error is within ± 2 cm, and the normal value error of lidar measurement is ± 2 cm, indicating that the system can effectively complete the measurement of road elevation information in front of the vehicle.

The identification error of this system mainly comes from three aspects. Firstly, it is the calibration error, because even if the external parameter calibration of the lidar is completed, there will also be some errors. For this part of the error, the lidar can be repeatedly calibrated by improving the calibration method. And analyzing the results of multiple calibrations can obtain a more accurate lidar pose. Secondly, the pose perception errors can be reduced by using high-precision positioning sensors and a pose-sensing algorithm that improves multi-sensor information fusion. Finally, it is the range error of the lidar when measuring distance. At present, the ranging accuracy of most lidar is not up to

millimeter level. By using a higher precision lidar, the system can effectively reduce the system identification error.

5. Conclusion

In this paper, the reconstruction of the road surface is carried out, and the point cloud data collected by the lidar is merged with the real-time pose of the lidar to realize the establishment of the 3D point clouds of the road surface, and then the point clouds are preprocessed through the point cloud library (PCL). The extraction of the point clouds of the road surface is based on the Kriging model to complete the construction of the road surface in front of the vehicle. In the end, the test results and reasons for error is analyzed by comparing with the actual road surface and the constructed road surface.

Acknowledgments

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