USING MOBILE LIDAR POINT CLOUDS FOR TRAFFIC SIGN DETECTION AND SIGN VISIBILITY ESTIMATION

Shuang Wu[1], Chenglu Wen[1], Huan Luo[1], Yiping Chen[1], Cheng Wang[1] and, Jonathan Li[1,2]*

1 Fujian Key Laboratory of Sensing and Computing for Smart Cities, Xiamen University, Xiamen, Fujian 361005, China

2 Department of Geography and Environmental Management, University of Waterloo, Waterloo, Ontario N2L 3G1, Canada

clwen@xmu.edu.cn

ABSTRACT

This paper presents a novel method for traffic sign detection and visibility evaluation from mobile Light Detection and Ranging (LiDAR) point clouds and the corresponding images. Our algorithm involves two steps. Firstly, a detection algorithm based on high retro-reflectivity of the traffic sign from the MLS point clouds is designed for sign detection in complicated road scenes. To solve the spatial features of traffic signs, we also create geo-referenced relations between traffic signs and roads according to the normal of ground. Secondly, we propose a visibility estimation method to evaluate the visibility level of the traffic sign based on a combination of visual appearance and spatial-related features. The proposed algorithm is validated on a set of transportation-related point-clouds acquired by a RIEGL VMX-450 LiDAR system. The experiment results demonstrate that the efficiency and reliability of the proposed algorithm in detection traffic signs are robust, and also prove the potential of using mobile LiDAR data for traffic sign visibility evaluation.

***Index Terms*—** Traffic sign detection, mobile LiDAR point clouds, sign visibility, feature extraction

1. INTORDUCTION

Traffic sign provides information and instructions to road users, and its usability and visibility finally affect the traffic safety. Traffic sign detection is an essential part of intelligent transportation systems, and the relevant research can provide effective methods to reduce potential traffic accidents and improve road safety. Current traffic sign detection and recognition researches are mainly based on traffic sign images and videos considering the ordinary shapes and standard colors exhibited by the signs [1-3]. However, there are many variability factors in the traffic sign data. The images and videos are captured in uncontrolled situations, such as occlusions, limited visibility caused by adverse heavy foggy weather, or illumination conditions. Bad sign visibility may cause driver distraction and increase the risk of a traffic accident, and affect the road safety of the road users. There are some published results related to traffic sign visibility estimation in foggy area [4-7] and camera-based sign visibility estimation [8-9]. For these key factors affecting traffic sign visibility status, the spatial-related parameters (e.g. sign placement, sign pose) need be especially concerned.

Mobile LiDAR point clouds has been applied to a variety of applications, such as road infrastructure and traffic facility information extraction [10-12]. With the development of LiDAR technology, Mobile Laser Scanning (MLS) system has become a promising mean to conduct land-based surveying and mapping. Due to the advantages of high-density and long-range properties of MLS LiDAR data, there is a potential to apply the MLS systems to traffic sign detection and sign visibility estimation.

In this paper, we propose a novel method for traffic sign detection and sign visibility estimation based on mobile LiDAR point clouds and the corresponding images. We particularly focus on the combination of features extracted from the point clouds and images respectively. By analyzing these combined features, we estimate the traffic sign visibility. The paper is organized as follows. Section II introduces the proposed method in detail. Section III gives experimental results and discussion. The paper gives a conclusion in Section IV.

2. METHODOLOGY

The proposed method contains following three main parts as: (1) traffic sign area detection on LiDAR point clouds and images; (2) spatial-related features and image features extractions; and (3) traffic sign visibility estimation. The flowchart of the proposed method is shown in Fig. 1,

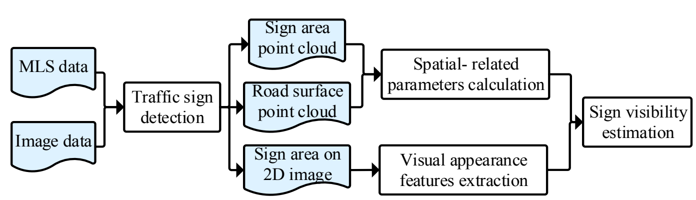

Fig. 1. Flowchart of the proposed sign detection and visibility estimation method.

2.1. Traffic sign detection

Traffic sign detection is performed on LiDAR point clouds and images. For traffic sign surface detection on LiDAR point clouds, traffic sign targets are firstly extracted from the point cloud scene using the methods presented in our previous work [13]. Firstly the associated road surface is filtered. As observed from the point clouds data, the traffic sign surface of point clouds is a vertical plane, which has the peculiarity of highly retro-reflective. Then, the traffic sign surface is extracted from point clouds by reflectance and geometric characteristic. The geometric characteristic of point clouds is calculated by the following equation:

$$M_{p_i} = [\overrightarrow{e_1} \quad \overrightarrow{e_2} \quad \overrightarrow{e_3}] \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \begin{bmatrix} \overrightarrow{e_1} \\ \overrightarrow{e_2} \\ \overrightarrow{e_3} \end{bmatrix}, \tag{1}$$

where the maximal eigenvalue (λ_1) of the local covariance matrix (M_{p_i}) of a linear structure is far greater than the second and the minimal eigenvalues (λ_2 and λ_3).

Based on the detected traffic sign area in LiDAR point clouds, on-image sign area detection is implemented by projecting the 3D points of each traffic sign onto a 2D image region that embodies this traffic sign. The procedure of traffic sign extraction is shown in Fig. 2. The traffic sign point cloud scene and corresponding image are shown in Fig.2 (a) and Fig 2. (b). The point cloud with road surface filtered is shown in Fig. 2 (c). Using the proposed sign detection method, the detected traffic sign surface in point clouds and image are shown in Fig. 2(d) and Fig. 2(e).

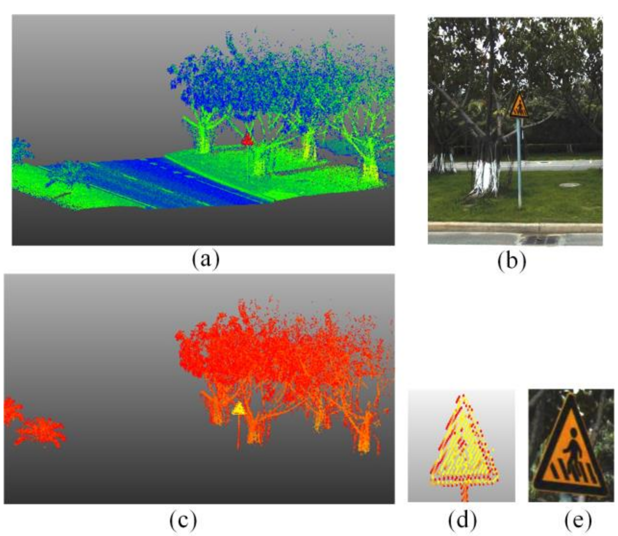

Fig. 2. An example of traffic sign detection. (a) traffic sign point cloud. (b) traffic sign image. (c) road surface filtered. (d) sign detected in point cloud. (e) sign detected in image.

2.2. Spatial-related features and image features extraction

The spatial-related features and image features are obtained from the detected traffic sign point clouds and image respectively.

2.2.1. Spatial-related features extraction

In general, the traffic signs are distributed in various positions and poses in a traffic environment. It's hard to achieve the 3D positioning and pose information from image directly, however it is easy to obtain these information using the geo-referenced relations between traffic signs and road achieved from mobile LiDAR point clouds.

Spatial-related features extracted in this method include four parameters s_1, s_2, s_3, s_4. s_1 is the distance from the driver's viewpoint to the traffic sign; s_2 represents the inclination of the traffic sign with respect to the road surface; s_3 describes the inclination of the traffic sign with respect to the viewpoint; s_4 represents the planarity of the traffic sign. We obtain the features value s_1, s_2 and s_3 using the following formulas:

$$s_1 = \sqrt{(x_v - x_s)^2 + (y_v - y_s)^2 + (z_v - z_s)^2}\ , \tag{2}$$

$$s_2 = \cos^{-1}\left(\frac{\overrightarrow{vs} * \overrightarrow{f}}{\|\overrightarrow{vs}\| \|\overrightarrow{f}\|}\right), \tag{3}$$

$$s_3 = \cos^{-1}\left(\frac{\overrightarrow{e_z} * \overrightarrow{f}}{\|\overrightarrow{e_z}\| \|\overrightarrow{f}\|}\right), \tag{4}$$

$$\overrightarrow{vs} = (x_v - x_s, y_v - y_s, z_v - z_s)\ . \tag{5}$$

The coordinate of the viewpoint is (x_v, y_v, z_v). The 3D parameters of traffic sign include center-of-mass coordinate (x_s, y_s, z_s) and surface normal $\overrightarrow{f} = (x_f, y_f, z_f)$. $\overrightarrow{e_z}$ is the ground normal. We use method in [13] to obtain the planarity features s_4.

2.2.2. Image features extraction

Intensity and color contrast affect the visibility of a traffic sign [8]. In addition, the size of the traffic sign and the edge contrast with complex background texture [9] also influence the traffic sign visibility.

In proposed method, the four image features including the intensity, the contrast of the color histogram, edge contrast, and the proportion of traffic sign, are calculated. We formulate these image features to be a feature vector (a_1, a_2, a_3, a_4). a_1 represents the percentage of a traffic sign in the whole image, a_2 represents the diversity between the edge strength in the sign region and that in background region, a_3 is the distance between the average color in the sign region and others sub-region in the image, a_4 represents the similarity between the color histogram in the sign region and other sub-region.

The feature vector (a_1, a_2, a_3, a_4) is calculated using the following four equations:

$$a_1 = \frac{A_{(S)}}{A}, \tag{6}$$

$$a_2 = \left|Es - E\right|, \tag{7}$$

$$a_3 = \sqrt{(Rs-R)^2 + (Gs-G)^2 + (Bs-B)^2}, \tag{8}$$

$$a_4 = \sqrt{\{D_{(R)}\}^2 + \{D_{(G)}\}^2 + \{D_{(B)}\}^2}, \tag{9}$$

where $A_{(S)}$ and A are the size of traffic sign and entire image respectively. Es and E are the average edge strengths calculated with Sobel filter in the sign region and other regions respectively. (Rs, Gs, Bs) and (R, G, B) are the average RGB values in the sign region and other regions respectively. $D_c(c \in \{\text{R, G, B}\})$ is the Bhattacharyya distance[8] defined by Eq. (10).

$$\{D(c)\} = \sum(\sqrt{H_s(c)} - \sqrt{H(c)}) \tag{10}$$

$H_s(c)$ represents the histogram of RGB channels in sign region, and *H(c)* represents the histogram of RGB channels in other regions.

2.3. Sign visibility estimation using feature combination

Inspired by [8], our proposed method uses a feature vector $f = (s_1, s_2, s_3, s_4, a_1, a_2, a_3, a_4)$, which integrates the spatial-related features and the image features, for traffic sign visibility estimation.

The accumulative visibility value V_c is calculated by:

$$V_c = \frac{1}{N}\sum_{t=0}^{N-1}\sum_{d=1}^{D} w_d M_d\,(f^t), \tag{11}$$

$$w_d = (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8), \tag{12}$$

$$\sum_{i=1}^{i=8} w_i = 1, \tag{13}$$

where N represents number of scene, w_d is a positive weighted vector for the basis function vector $M_d(f)$. Higher value of V_c means better visibility of a traffic sign.

3. EXPERIMENTS AND DISCUSSIONS

The traffic sign MLS data (LiDAR point clouds and images) used in our experiments were acquired by a RIEGL VMX 450 system. The VMX 450 system integrated with two RIEGL VQ-450 laser scanners, four high-resolution digital cameras, a GNSS, an IMU, and a wheel-mounted distance measurement indicator (DMI). The acquired traffic sign data contain one hundred traffic scenes, which distribute in the Ring Road and Zhongshan Road in Xiamen, China. Each traffic scene includes one or two traffic signs.

Some results generated by our traffic sign detection method are given in the Fig. 3.

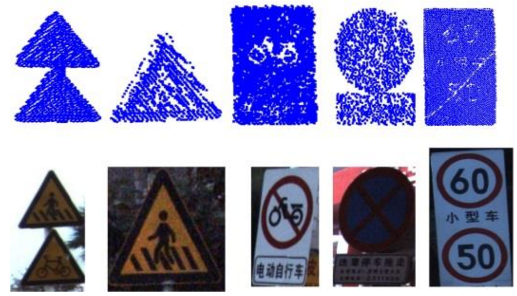

Fig. 3. Some examples of traffic sign detected.

3.1. Traffic sign visibility evaluation criteria

For each traffic sign scene, our method gave an visibility estimation value V_c. Then we normalized all the visibility values into the range of (0, 1). To evaluate the proposed estimation method, we compared these results with the subjective evaluation results.

For subjective visibility evaluation, we set 4 evaluation categories of invisibility (category 1), low visibility (category 2), medium visibility (category 3) and high visibility (category 4). For each sign scene, the subjective visibility value were obtained by averaging the evaluation results from 30 people. The averaged results of subjective visibility evaluation of the 100 traffic sign scenes are shown in Table I.

Table I Subjective evaluation results for traffic sign visibility

Visibility level	Invisibility	Low visibility	Medium visibility	High visibility
category	1	2	3	4
Sign number	15	26	37	22

3.2. Experiment Results

The visibility estimation values were obtained for all the 100 traffic sign scenes. Higher V_c value represents better visibility, and lower V_c value represents worst visibility. Some examples of traffic sign scene and its calculated visibility values V_c are given in Fig. 4. It was observed from Fig. 4 that lower V_c value was obtained with more complicated background. Higher V_c value was obtained with closer distance between the sign and the driver. These results match the concept that complicated background and observing distance will affect the visibility of a traffic sign.

We normalized all the calculated estimation values into the range of (0, 1) by setting the minimum estimation value as 0 and the maximum estimation value as 1. Then we manually set thresholds to rearrange the calculated results into four categories. The process of threshold setting are described as follows. When the calculated result is in the range of (0, 0.25), its visibility value is set to 1. When the calculated result is in the range of (0.26, 0.50), its visibility value is set to 2. When the calculated result is in the range of (0.51, 0.75), its visibility value is set to 3. When the calculated result is in the range of (0.76, 1), its visibility value is set to 4. We compared the calculated results with the results shown in Table I to see the difference between the calculated results and subjective evaluation results. The comparison is given in Fig. 5.

Fig. 4. Some examples of visibility estimation values calculated.

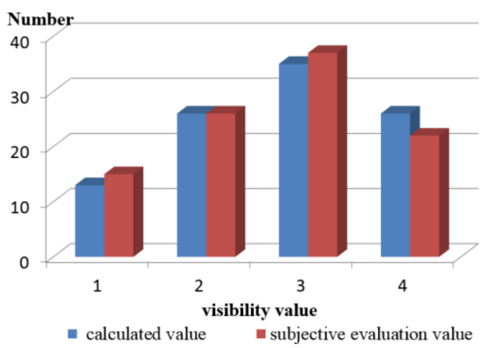

Fig. 5. The statistical histogram

As shown in Fig. 5, our calculated results are close to the subjective evaluation results. The average deviation between the calculated results and subjective evaluation are under 5%. It demonstrates that our visibility estimation method is effective. Here, we focus on the situation of the stationary traffic scenes. Actually, the position of a vehicle changes when the vehicle moves. At the same time, the spatial-related features, such as observing distance and observing angle change too. It will be interesting to analyze the change of the estimated traffic sign visibility with the moving of the vehicle based on mobile LiDAR data.

4. CONCLUSION

This paper proposed a novel traffic sign detection and visibility estimation method, which integrates the spatial-related features and image features extracted from point clouds and images. The visibility estimation results by our method match the subjective evaluation results well. The experimental results demonstrated that the proposed method has a potential to estimate the visibility of traffic sign.

References

[1] A. Møgelmose, M. M. Trivedi, and T. B. Moeslund, “Vision based traffic sign detection and analysis for intelligent driver assistance systems: perspectives and survey,” IEEE Trans Intell. Transp. Syst., vol. 13, no. 4, pp 1484-1497, 2012.

[2] S. Šegvić, K. Brkić, Z. Kalafatić, and A. Pinz, “Exploiting temporal and spatial constraints in traffic sign detection from a moving vehicle,” Mach. Vision Appl., vol. 25, no. 3, pp. 649-665, 2011.

[3] Á. González, L. M. Bergasa, J. J. Yebes, “Text detection and recognition on traffic panels from street-level imagery using visual appearance,” IEEE Trans Intell. Transp. Syst., vol.15, no. 1, pp. 228-238, 2014.

[4] C. Li, H. Feng, X. Zhi and N. Zhao, “Intelligent Guidance System for Foggy Area Traffic Safety Operation,” 2011 14th International IEEE Conference on Intell. Transp. Syst., DOI:10.1109/ITSC.2011.6082920.

[5] D. Wu and X. Deng, “Forecast system of visibility at speedway area at Nanling Mountains,” J. Trop. Meteor., vol. 22, no. 5, pp. 417-422, 2006.

[6] P. Siegmann, S. Lafuente-Arroyo, S. Maldonado-Bascon, P. GilJimenez, and H. Gomez-Moreno, “Automatic evaluation of traffic sign visibility using SVM recognition methods,” in Proc. 5th WSEAS Int. Conf. on Signal Processing, Computational Geometry & Artificial Vision, pp. 170-175, 2005.

[7] L. Simon, J.-P. Tarel, and R. Bremond, “Alerting the drivers about road signs with poor visual saliency,” in Proc. 2009 IEEE Intell. Vehicles Symp, pp. 48-53, 2009.

[8] K. Doman, D. Deguchi, T. Takahashi, Y. Mekada, I. Ide, H. Murase, and Y. Tamatsu, “Estimation of traffic sign visibility toward smart driver assistance,” in Proc. 2010 IEEE Intell. Vehicles Symp, pp. 45-50, 2010.

[9] K. Doman, D. Deguchi, T. akahashi, Y. Mekada, I. Ide, H. Murase, and Y. Tamatsu, “Estimation of Traffic Sign Visibility Considering Temporal Environmental Changes for Smart Driver Assistance,” in Proc. 2011 IEEE Intell. Vehicles Symp, pp. 667-672, 2011.

[10] S. Pu, M. Rutzinger, G. Vosselman, and S. O. Elberink, “Recognizing basic structures from mobile laser scanning data for road inventory studies,” ISPRS J. Photogramm. Remote Sens., vol. 66, no. 6, pp. 28-39, 2011.

[11] H. Guan, J. Li, Y. Tao, M. Chapman and C. Wang, “Automated road information extraction from mobile laser scanning data,” IEEE Trans Intell. Transp. Syst., vol. 16, no. 1, pp. 194-205, 2015.

[12] P. Musialski, P. Wonka, D. G. Aliaga, M. Wimmer, L. van Gool, and W. Purgathofer, “A survey of urban reconstruction,” Comput Graph Forum, vol. 32, no. 6, pp. 146-177, 2013.

[13] C. Wen, J. Li, H. Luo, Y. Yu, Z. Cai, H. Wang, and C. Wang, “Spatial-related traffic sign inspection for inventory purposes using mobile laser scanning data,” IEEE Trans Intell. Transp. Syst., DOI:10.1109/TITS.2015.2418214.