Rebar Diameter Classification using Scan Planning

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Abstract
Inspecting rebar diameter and rebar spacing prior to concrete pouring is an important task to ensure bearing capacity and structural integrity of the reinforced concrete elements. This study presents a novel scan planning method that determines optimal laser scanner position for accurate rebar diameter classification. First, a geometrical relationship model that simulates the coordinates of scan points on the rebar layers is developed. Second, a scan planning method using the geometrical relationship model is proposed to determine the optimal laser scanner location. To validate the model and scan planning method, experimental tests were performed on a laboratory-scale rebar layout and the results show a rebar diameter prediction accuracy of 90.1%, demonstrating the potential for the application in manufacturing and construction sites.

Keywords: Scan planning, rebar diameter classification, laser scanning

1 Introduction
Inspection of rebar spacing and diameter is an essential task for quality assessment of reinforced concrete (RC) elements prior to concrete pouring during the manufacturing and construction stage (Han et al. 2013; Wang et al. 2017). This is attributed to that bearing capacity and structural integrity of the RC elements are dedicated by the installation of the rebar (Nishio et al. 2016; Golparvar-Fard et al. 2012). Therefore, rebars installed in the reinforced concrete structures should be consistent with the position and size specified in the designed document before concrete pouring. Normally, inspection of rebar diameter and rebar spacing are performed manually by the qualified workers using measurement tapes, which are time-consuming, labor intensive and prone to human errors (Golparvar-Fard et al. 2012; Akula et al. 2013). To ensure compliance with contract documents and building codes, it is necessary to develop an automatic and accurate technique to assess rebar diameter and rebar spacing for reinforced concrete structures. Recently, terrestrial laser scanner (TLS) has been considered as a promising data acquisition technology to inspect rebar diameter and spacing because it is a non-contact and accurate measurement sensor. However, poor performance on small-size rebar classification caused by low scan density is still challenging to be addressed since high scan density is difficult to be guaranteed on small size rebar (Kim et al. 2020; Kim et al. 2021). To tackle the current limitations, this study aims to present a TLS-based scan planning method to determine the optimal laser scanner location for accurate rebar diameter prediction.

The remainder of paper is organized as follows. First, introduction and research background related to rebar inspection in the construction industry is presented in Section 1. The overall scheme and its procedure of the scan planning method is described in Section 2, followed by experimental validation in Section 3. Lastly, this paper ends with a brief summary and future work in Section 4.

2 Methodology

Figure 1 shows the overview of the scan planning method for rebar diameter classification, which consists of three stages. The details of each stage are presented as follows.

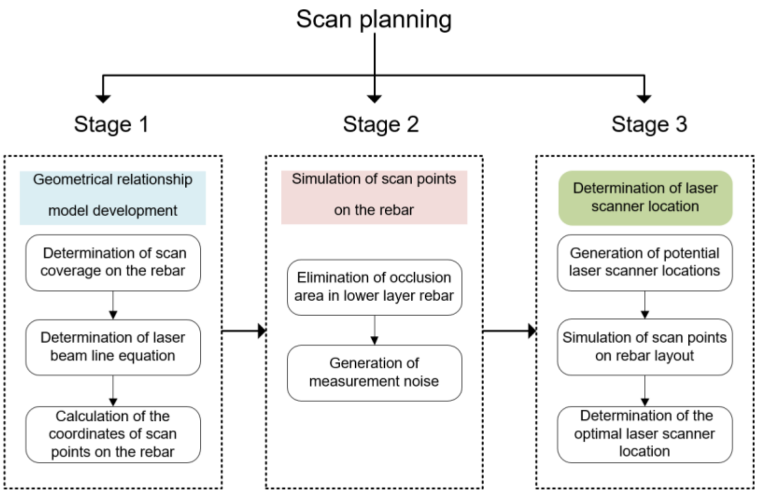

Figure 1. Overall procedure of the scan planning method for rebar diameter classification

Stage 1: This step aims to develop the geometrical relationship among the laser scanner, rebars and scan points on the rebar. Figure 2 shows the input and output diagram of the geometrical relationship model. The input parameters of the model include 1) the emitting point t (x_t, y_t, z_t) of the laser scanner and 2) the as-designed rebar layout information including rebar spacing (s) and rebar diameter (r) while the output of the model is the scan points $n_i(x_{n_i}, y_{n_i}, z_{n_i})$ located on the rebar. Here the rebar diameter input information is used for only developing the model to conduct the scan planning in this study.

Stage 2: This step aims to simulate scan points on rebar layout based on the developed geometrical relationship model. Note that the transversal rebars will cause occlusion at the connection area where between the longitudinal rebars and the transversal rebars. Therefore, the scan points within the occlusion area on the longitudinal rebars are necessary to be eliminated for simulation process. Then, the measurement errors are generated for each scan point based on the assumption that the measurement error compiles Gaussian Distribution (Davenport and Root 1958).

Stage 3: This step aims to determine the optimal laser scanner location. First, potential laser scanner locations are generated as the intersections of the 3D grid near the rebar layout. Then, the scan points are simulated for each potential laser scanner locations. Finally, the optimal laser scanner is determined as the location with the highest rebar diameter prediction accuracy.

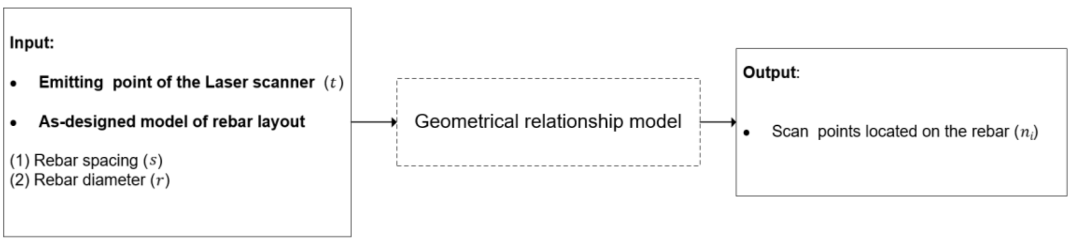

Figure 2. Input-and-output diagram of the geometrical relationship model

3 Validation

To further validate the effectiveness of the scan planning method, validation tests was conducted to compare the rebar diameter prediction accuracy between the simulated scan points and collected scan points.

3.1 Test configuration

Figure 3 shows the rebar layout used for the comparison test in 3D view. The specimen was manufactured with the dimensions of 2400 mm (length) × 900 mm (width) × 160 mm (height). The rebar layout is composed of 2 layers with 8 different rebar diameters of D40-D10. For each layer, there are 6 and 8 rebars in the longitudinal and transversal directions respectively. In addition, C-shape rebars were used to connect the top and bottom rebar layers. As for data acquisition, a phase-shift TLS, FARO M70, with a range measurement accuracy of ±3 mm at 20 m was used to acquire scan points of the specimen. In addition, angular resolutions of 0.018° is employed for the tests.

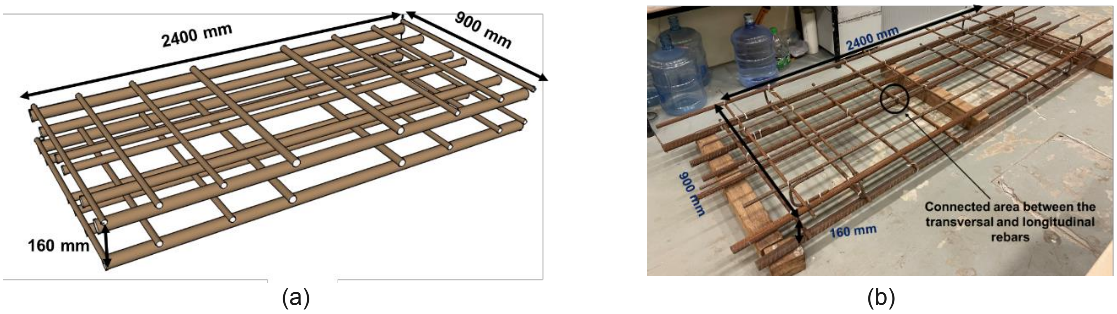

Figure 3. Rebar layout used for the comparison test: (a) as-designed model and (b) lab-scale specimen.

3.2 Results

Figure 4 (a) shows the generation of potential laser scanner locations above the rebar layout. First, 3D grid with a resolution of 0.5 m (length) ×0.5 m (width) × 0.2 m (height), which is sufficiently dense is selected to generate potential laser scanner locations. Then, evaluation of the performance for each location was conducted by simulating the scan points on rebar layout for each potential laser scanner location. Then, rebar diameter prediction accuracy $Acc\ (i)$ was calculated for each potential laser scanner location. Finally, the location of (0.5 m, 1.5 m, 1.2 m) with the highest rebar diameter prediction accuracy of 90.1% is determined as the optimal laser scanner location. Figure 4 (b) shows the selected 3 laser scanner locations in 2D view to compare the simulated scan points and the collected scan points. Table 1 shows the comparison of rebar diameter prediction accuracy between simulated scan points and collected scan points. It is observed that similarity of rebar diameter prediction accuracy is more than 90% between the simulated scan points and collected scan points. From these results, it is also found that the scan density has relative lower similarity between the simulated scan points and collected scan points compared to the scan coverage.

4 Conclusion

This study presents a novel laser scanning based scan planning method to determine the optimal laser scanner location for accurate rebar diameter prediction. First, a geometrical relationship model that simulates the coordinates of scan points located on the rebar layers is developed. Second, a novel scan planning is proposed to determine the optimal laser scanner location for accurate estimation of rebar diameter. To further investigate the feasibility of the proposed scan planning method, validation experiment was performed to determine laser scanner location for rebar diameter prediction. The determined laser scanner location using the proposed scan planning method provides rebar diameter prediction accuracy of 90.1% for rebar diameter D40-D10, demonstrating the great potential for the application of the proposed technique for rebar inspection in manufacturing and construction stage. The key contributions of the study include 1) the development of the geometrical relationship model considering the geometrical relationship between laser scanner location and rebar layout to simulate scan points located on the rebar layout; and 2) the proposal of a new scan planning method to determine the optimal laser scanner location to guarantee accurate rebar diameter prediction.

However, limitations remain to be addressed in the future studies. First, the test specimen used in this study is a lab-scale one, so further study is necessary in order to investigate the applicability of the proposed technique to large-scale or full-scale elements. Second, the proposed technique is focused on rebar layout inspection of reinforced concrete elements manufactured in the factory and further tests can be extended on rebar layout in other construction components on site.

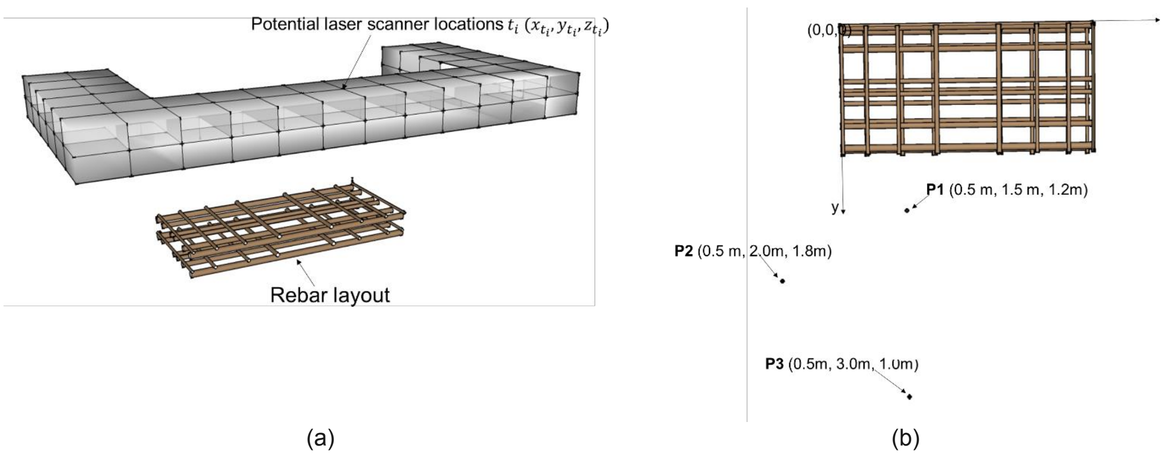

Figure 4. Selected 3 laser scanner location for comparison. (a) Generation of potential laser scanner locations in 3D grid and (b) Selected 3 laser scanner locations in 2D view.

Table 1. Comparison of rebar diameter prediction accuracy between simulated scan points and collected scan points

Position	**Object**	**Simulated scan points**		**Collected scan points**	
		Rebar level	Slice level	Rebar level	Slice level
Position 1 (0.5 m, 1.5 m, 1.2m)	Large diameter rebar (D40-D25)	100%	98.6%	100%	91.1%
	Small diameter rebar (D20-D12)	77.2%	72.9%	80.1%	75.0%
	Total rebar (D40-D12)	88.6%	81.0%	90.1%	83.1%
Position 2 (0.5 m, 2.0m, 1.8m)	Large diameter rebar (D40-D25)	100%	98.6%	100%	92.2%
	Small diameter rebar (D20-D12)	77.2%	63.1%	70.1%	58.2%
	Total rebar (D40-D12)	88.6%	75.0%	85.1%	75.2%
Position 3 (0.5 m, 3.0m, 1.8m)	Large diameter rebar (D40-D25)	83.3%	83.3%	83.3%	66.7%
	Small diameter rebar (D20-D12)	54.4%	48.6%	56.3%	47.3%
	Total rebar (D40-D12)	68.5%	60.0%	75.0%	57.2%

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