Sensors & Transducers, Vol. 186, Issue 3, March 2015, pp. 168-172

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Concrete Crack Measurement and Analysis Based on Terrestrial Laser Scanning Technology

Xiangyang Xu, * Hao Yang, Ingo Neumann
Geodetic Institute, Faculty of Civil Engineering and Geodetic Science,
Leibniz University Hanover, Nienburger Street 1. D-30167, Hanover, Germany
***** E-mail: Yang@gih.uni-hannover.de

Received: 29 December 2014 /Accepted: 19 March 2015 /Published: 31 March 2015

Abstract: Terrestrial laser scanning (TLS) has become one of the potential technologies for an object three-dimensional (3D) information acquisition. The using vibration analysis for early detection of cracks has gained popularity over the years and in the last decade substantial progress has been made in that direction. However, the crack detection using TLS is also a good method. In the experimental part of this study, the effect of crack width and location on modal properties of the beam was investigated. The recent paper provides a method for automatic concrete cracks detection from the data that was obtained by TLS. The method of cracks detection is achieved by six steps. The objective of this study is to analyze the crack of concrete beams both experimentally and using MATLAB analysis. Besides this, information about the width, location and percentage of cracks in cracked concrete beams can be obtained using this technique. *Copyright © 2015 IFSA Publishing, S. L.*

Keywords: TLS, Crack, Concrete, Point cloud, MATLAB.

1. Introduction

Terrestrial laser scanning (TLS) has become one of the potential technologies for object 3D information acquisition. The using vibration analysis for early detection of cracks has gained popularity over the years and in the last decade substantial progress has been made in that direction. However, the crack detection using TLS is also a good method. Dynamic characteristics of damaged and undamaged materials are very different. For this reason, material faults should be detected. An automatic crack detection of concrete surface is very effective for further processing. The crack information can be used to study material properties and prevent damage of the structure. In practice, cracks on concrete surfaces are traced manually for diagnosis. The automatic crack detection is highly desirable for an efficient and objective crack assessment. The behavior of a concrete structure can be studied by the experimental modal analysis. Behaviors of damaged and undamaged materials are very different. For this reason, material faults should be detected, especially in beams. A crack formation due to cycling loads leads to fatigue of the structure and to discontinuities in the interior configuration. Therefore, there is a need to understand the dynamics of cracked structures [1].

The recent paper describes a method for automatic concrete cracks detection from the data that was obtained by TLS. The method of cracks detection is achieved by six steps: getting the image of concrete surface intensity, graying, contrast enhancing, median filtering, binarization and denoising. In this study, the dynamic analysis based on the cracked concrete beam analysis was experimentally evaluated. In the experimental part of this study, the effect of crack width and location on modal properties of the beam was investigated.

1.1. Research State of the Art

In the recent years a wide range of models and applications have been proposed for crack analysis, and an impressive array of useful information has been accumulated. As a result, the theoretical basis of the discipline has been strengthened; a number of fundamental issues solved; and the range of applications widened [2].

Nowadays, TLS is often used in various fields such as civil engineering or archaeology for object modeling, geographic information system and so on. However, an application for system identification and structural health monitoring is in the beginning stage [3]. Rosser et al. [4] use TLS to monitor changes on coastal cliff faces. The results demonstrate that the terrestrial laser scanning can be used to quantify cliff failures to a previously unobtainable precision. Monserrat et al. [5] monitor land deformation using repeated TLS scans and estimate the deformation parameters using local surface matching. It is interesting to note that the results were achieved under non-optimal conditions, e.g. using non-calibrated data and sub-optimal targets from the matching viewpoint. Lee et al. [6] present health monitoring of structures using TLS and adopt a displacement measurement model to improve the accuracy of the measurement. Many techniques and devices for acquiring 3D information have been developed in the recent years [7-10]. As terrestrial laser scanners have become more available, their applications have become more widespread, creating a demand for affordable, efficient and user-friendly devices [11-14]. Several studies have analyzed the behavior of these instruments [15-18].

The concrete surface measurement of TLS is done by many researchers. Somebody convert point clouds into a consistent polygonal or mesh [19]. Vertices, edges, faces and so on are contained in this mesh surface. Tsakiri et al. [20] take advantage of planes fitted to point clouds when gauging the displacement. The plane model is suitable for small areas, thus the section is divided into grid cells. As for the monitoring of tunnel, Van Gosliga et al. [21] configure the tunnel model with a cylinder. Chang et al. [22] develop a program in order to analyze the structure surface. The surface data such as the degree of deformation is acquired easily by statistic regression and polynomial function. Karl-Rudolf Koch [23] fits a three dimensional NURBS [24] surface by the lofting method. It is shown that the lofting method for estimating the control points and their simultaneous estimation gives identical results for time-dependent problems.

1.2. Framework

This paper analyzes the cracks with the experiment on the behavior of concrete beams. Concrete structures are commonly designed to satisfy criteria of serviceability and safety. With the MATLAB software, we deal with every load beam as the work-flow shown in Fig. 1.

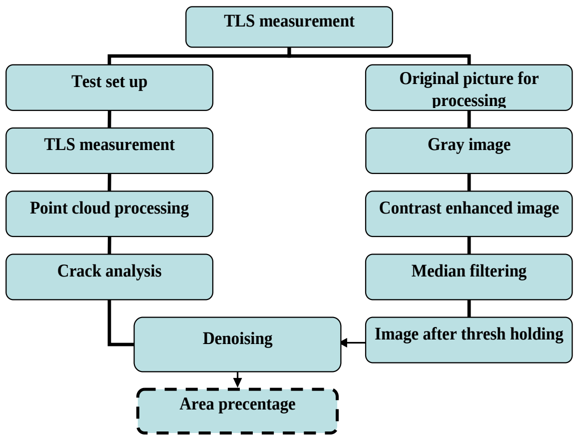


Fig. 1. The work-flow of crack analysis by MATLAB.

We have six steps in the Fig. 1: 1) The point cloud are collected by TLS measurement; 2) The original image extracted from the intensity of point cloud are required for processing; 3) We get the gray image; 4) The contrast of image is enhanced to extracted more clear cracks; 5) The median filtering method is used to smooth the cracks; 6) We gain the median image after thresh holding. 7) The noise is removed and two sides of beam are cut. 8) We calculate the area percentage of cracks in beam.

2. Experimental Setup and Data Analysis

This experiment (see Fig. 2) was carry out in order to observe cracking, displacement and other intricate concrete structural analysis. The loading method involved two cylinders fixed at both ends of a specimen. More information about parameters and types of the concrete are presented in [25].

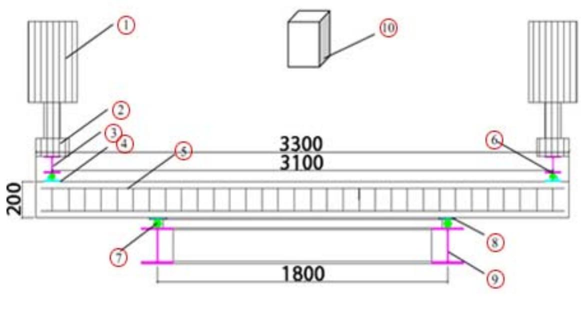


Fig. 2. Introduction of test setup [26]. Here: 1. Hydraulic jack; 2. Force sensors; 3. HEB 200 I-steel; 4. Steel plate of 5 mm; 5. Test specimen; 6. Steel tube (Diameter: 5 mm); 7. Steel tube (Diameter: 5 mm); 8. Steel plate of 5 mm; 9. I-steel frame (HEB 200); 10. Laser scanner.

The load increment was selected at 4 kN up to the formation of the first crack and then the load increment increased to 5 kN. Each load step was held for 5 minutes. The loading was continued until the ultimate load. More details about the measurement accuracy and resolution of TLS are described in [25]. The test setup is introduced in Fig. 2.

The tested slab-strips were carefully inspected at each load step. The load and deformation were measured by force sensors and laser displacement sensors. The triangular displacement sensors are in the middle position under the beam. The TLS obtains the point clouds of beam at every load step. The presented here experimental setup should provide an example for the general working steps and ideas in the paper. More information about the test is available in [25].

In this experiment, we attempt to investigate the load variation influence on the average and the maximum crack widths. It is noted in the test procedure that the crack widths were measured at each load increment up to the failure. In the paper, the discrepancy of an inverse trend between crack spacing and width with the principles in current codes was found (see Fig. 3).

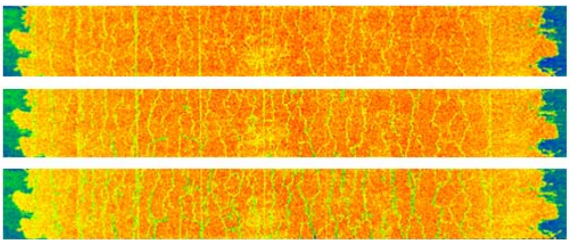
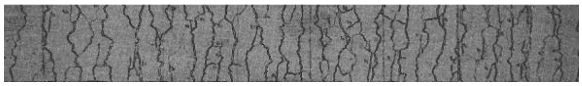


Fig. 3. The crack of concrete beam test by TLS.

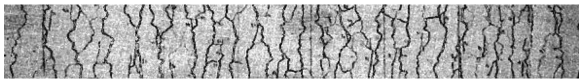
The TLS measurement collects the information of point clouds, which includes x, y, z coordinates and intensity. We obtain the intensity value of laser reflected from the loaded beam, which is sharply different between cracks area and non-crack area. Therefore, we observe the intensity image with the green curves as cracks in Fig. 3, where the force from top to bottom plots correspond to 43.60 kN, 54.52 kN and 58.92 kN. It is indicated that the crack width and percentage are increasing with the load.

3. Crack Analysis

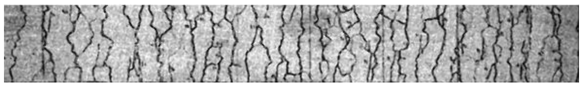
Generally, a crack width is the length of the line joining two its edges; this line is perpendicular to the medial axis of the crack. “Sometimes, it is difficult to determine the actual crack orientation by visual inspection because it is difficult to locate the medial axis of the crack. In this study, the crack width is defined as the distance between two edges on a line parallel to the normal vector of the medial axis of the crack, whereas the crack orientation is defined as the tangent vector of the medial axis” [27]. In order to state the processing of MATLAB software clearly, we present beam cracks with 65kN load step by step in Fig. 4.



(a) Gray image of crack beam



(b) Contrast enhanced image of crack beam



(c) Wave filtering of crack beam

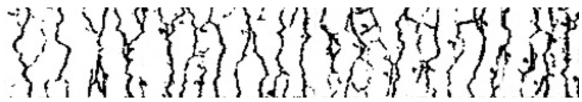
(d) Image of crack beam after thresh holding

Fig. 4. The cracks of beams step-processing with MATLAB.

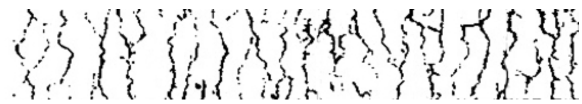
The cracks of beams step-processing with MATLAB is shown in Fig. 4. It has been stated in the workflow with the six main steps: intensity extraction corresponds to Fig. 3, graying corresponds to the plot (a), contrast enhancing corresponds to the plot (b), median filtering corresponds to the plot (c), binarization corresponds to plots d and denoising will be present in Fig. 5.

As we can see in the figure, the noise is too high especially at the sides of the beams. We decide to delete the high noise sides and reduce the noise. The results are shown in Fig. 9, where the plot (a) is the result of crack with 58.92 kN load which deal with MATLAB; the plot (b) corresponds to 54.52 kN and the plot (c) corresponds to 43.60 kN.

(a) The cracks of beam with 58.92 kN load



(b) The cracks of beam with 54.52 kN load



(c) The cracks of beam with 43.60 kN load

Fig. 5. The crack beams with different loads after noise reduction.

According to the Fig. 5, we can observe the number of crack is not increasing, but the cracks are wider. Therefore, when the load exceeds a critical value, the number of crack is invariant but the width of cracks are increasing with the loads. The percentage of crack areas and the crack width, which calculated as 30 ± 3 cracks, are listed in Table 1.

Table 1. The results of cracks' dimensions.

Epoch data	Area ratio of the crack	Number	Width
Crack of epoch 9	8.06 %	28±3	8.6±0.8 mm
Crack of epoch 8	4.85 %	28±3	5.2±0.5 mm
Crack of epoch 7	2.60 %	28±3	2.8±0.3 mm

After all above processing, we can obtain the area percentage ratio of the cracks and compare with the different loads. The crack area is increasing with the load, which could be confirmed by the Table 1. It is hinted that the width of cracks are proportional to the area of cracks.

4. Conclusions

The recent paper presents a method for automatic concrete cracks detection in normally surveyed TLS data. The measurement accuracy and resolution of TLS is high enough for this application. By utilizing TLS in a survey process, the real objects can be represented more adequately than through a single picture or collection of pictures. A method for the efficient recognition of concrete surface cracks using data provided by TLS observations has been developed and implemented in MATLAB. We should remember that nowadays traffic is continuously increasing over all of the world, especially in some developing countries [28]. The resulted models can currently be used for as-built documentation applications.

This paper proposes an innovative image processing method for detecting cracks on a concrete surface. The proposed crack detection is divided into six main parts: intensity extraction, graying, contrast enhancing, median filtering, binarization, denoising. The image processing technique described in this study enables objective and quantitative inspection of cracks on concrete surfaces. Using this method, the characteristics of cracks such as crack width can be effectively determined within a short time.

Acknowledgments

The authors wish to acknowledge the support of all the colleagues in Geodetic Institute of Leibniz University Hanover for their valid information and nice help. We acknowledge support by Deutsche Forschungsgemeinschaftand Open Access Publishing Fund of Leibniz Universität Hannover. Xiangyang Xu is supported by China Scholarship Council.

References

[1]. Chati M., Rand R., Mukherjee S. Modal analysis of a cracked beam, *Sound Vib*, 207, 2, 1997, pp. 249-70.

[2]. Shi, Z. H. Crack Analysis in Structural Concrete: Theory and Applications, *Library of Congress Cataloging-in-Publication Data*, 2009, pp. 25-56.

[3]. Kang, D. S., Lee, H. M., Park, H. S., Lee, I. Computing Method for Estimating Strain and Stress of Steel Beams Using Terrestrial Laser Scanning and FEM, *Key Engineering Materials*, Vol. 347, 2007, pp. 517-522.

[4]. Rosser, N. J., Petley, D. N., Lim, M., Dunning, S. A., Allison, R. J. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion, *Quarterly Journal of Engineering Geology and Hydrogeology38*,November,2005, pp. 363-375.

[5]. Monserrat, O., Crosetto, M. Deformation measurement using terrestrial laser scanning data and least squares 3D surface matching, *ISPRS Journal of Photogrammetry & Remote Sensing*, 63, 2008, pp. 142-154.

[6]. Park, H. S., Lee, H. M., Hojjat A., Lee, I. A New Approach for Health Monitoring of Structures: Terrestrial Laser Scanning, *Computer-Aided Civil and Infrastructure Engineering*, Vol. 22, Issue 1, January 2007, pp. 19-30.

[7]. S. W. Park, H. S. Park, J. H. Kim, Hojjat Adeli, 3D displacement measurement model for health monitoring of structures using a motion capture system, *Measurement*, 2015, 59, pp. 352-362.

[8]. Guangcong Zhang, Patricio A. Vela, Peter Karasev, Ioannis Brilakis, A Sparsity-Inducing Optimization-Based Algorithm for Planar Patches Extraction from Noisy Point-Cloud Data, *Computer-Aided Civil and Infrastructure Engineering*, 2014, 29, pp. 86-102.

[9]. Wei Zhang, Ke Sun, Changzheng Lei, Yuncong Zhang, Huixin Li, Bill F. Spencer, Fuzzy Analytic Hierarchy Process Synthetic Evaluation Models for the Health Monitoring of Shield Tunnels, *Computer-Aided Civil and Infrastructure Engineering*, 2014, 29, 9, pp. 676–688.

[10]. M. B. Nigro, S. N. Pakzad, S. Dorvash, Localized Structural Damage Detection: A Change Point Analysis, *Computer-Aided Civil and Infrastructure Engineering*, 29, 6, 2014, pp. 416–432.

[11]. Faisal Shabbir, Piotr Omenzetter, Particle Swarm Optimization with Sequential Niche Technique for Dynamic Finite Element Model Updating, Computer-Aided Civil and Infrastructure Engineering, 2014, 29, 10, pp. 10-15.

[12]. Marco Torbol, Real-Time Frequency-Domain Decomposition for Structural Health Monitoring Using General-Purpose Graphic Processing Unit, *Computer-Aided Civil and Infrastructure Engineering*, 29, 9, 2014, pp. 689-702.

[13]. Sara B. Walsh, Daniel J. Borello, Burcu Guldur and Jerome F., Hajjar Data Processing of Point Clouds for Object Detection for Structural Engineering Applications, Computer-Aided Civil and Infrastructure Engineering, 29, 10, 2014, pp. 495-508.

[14]. Choi, S. W., Kim, B. R., Lee, H. M., Kim, Y., Park, H. S., A Deformed Shape Monitoring Model for

Building Structures Based on a 2D Laser Scanner, *Sensors*, 2013, pp. 6746-6758.
[15]. Kasperski, J., Delacourt, C., Allemand, P., Potherat, P., Jaud, M., Varrel, E., Application of a Terrestrial Laser Scanner (TLS) to the Study of the Séchilienne Landslide, *Remote Sens.*, 2010, pp. 2785-2802.
[16]. Park, J. H., Shim, J., Lee, D. Y. A Compact Vertical Scanner for Atomic Force Microscopes, *Sensors*, 2010, pp. 10673-10682.
[17]. Raumonen, P., Kaasalainen, M., Åkerblom, M., Kaasalainen, S., Kaartinen, H., Vastaranta, M., Holopainen, M., Disney, M., Lewis, P., Fast Automatic Precision Tree Models from Terrestrial Laser Scanner Data, *Remote Sens.*, 2013, pp. 491-520.
[18]. Belgiu, M., Tomljenovic, I., Thomas J. L., Blaschke, T., Höfle, B. Ontology-Based Classification of Building Types Detected from Airborne Laser Scanning Data, *Remote Sens.*, 2014, pp. 1347-1366.
[19]. Edelsbrunner, H. Geometry and Topology for Mesh Generation, volume 6 of Cambridge. Monographs on Applied and Computational Mathematics, *Cambridge University Press*, UK, 2001.
[20]. Tsakiri M., Lichti D., Pfeifer N. Terrestrial Laser Scanning for Deformation Monitoring, in *Proceedings of the 3rd IAG/12th FIG Symposium*, 2006, pp. 22-24.
[21]. Van Gosliga, R., Lindenbergh, R., Pfeifer, N., Deformation analysis of a bored tunnel by means of terrestrial laser scanning, *International Archives of Photogrammetry*, 2006, pp. 81-89.
[22]. Chang, Y., LAI, S., Peng, S., Chang, K., Non-Contact Bridge Deflection Measurement: Application of Laser Technology, Integrating Generations FIG Working Week 2008, Stockholm, Sweden, June 2008, pp. 14-19.
[23]. Koch, K. Three-dimensional NURBS surface estimated by lofting method, *J. Adv. Manuf. Technol.*, 2010, pp, 49-68.
[24]. Piegl, L., Tiller, W. the Nurbs book, *Springer*, 1997, 12-85.
[25]. Yang, H., Xu, X. Y., Neumann, I., The Benefit of 3D Laser Scanning Technology in the Generation and Calibration of FEM Models for Health Assessment of Concrete Structures, *Sensors*, 2014, pp. 21890-21903.
[26]. Han, D., Experimental and Theoretical Investigation of the Crack Behavior of RC-slabs Subjected to Biaxial Bending, *Universität der Bundeswehr München*, Munich, Germany, 2011.
[27]. Nishikawa, T., Yoshida, J., Sugiyama, T., Fujino, Y. Concrete Crack Detection by Multiple Sequential Image Filtering, *Computer-Aided Civil and Infrastructure Engineering*, 27, 2012, pp. 29-47.
[28]. Hansen, M., Haar, C., Marx, S., Assessment of heavy load vehicles without disability of traffic, in *Proceedings of the 8th Central European Congress on Concrete Engineering (CCC'12)*, October 2012, pp. 169-174.