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TRƯỜNG ĐẠI HỌC DUY TÂN
DUYTAN UNIVERSITY

Applications of Gaussian Steerable Filters in detecting structural damages

Ứng dụng các bộ lọc có hướng Gaussian trong việc phát hiện các khuyết tật trên bề mặt kết cấu

Hoàng Nhật Đức[a,b]
Hoang Nhat Duc[a,b*]

[a]*Institute of Research and Development, Duy Tan University, Da Nang, 550000, Vietnam*
[a]*Viện Nghiên cứu và Phát triển Công nghệ Cao, Đại học Duy Tân, Đà Nẵng, Việt Nam*
[b]*Faculty of Civil Engineering, Duy Tan University, Da Nang, 550000, Vietnam*
[b]*Khoa Xây dựng, Trường Đại học Duy Tân, Đà Nẵng, Việt Nam*

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Abstract

Periodic structural health survey is very crucial to guarantee the safety and serviceability of civil engineering structures. This study aims at developing a computer vision tool to detect defects on surface of civil engineering structures by means of Gaussian steerable filters. This tool has been developed with Visual C#. NET to facilitate its implementations. The developed software programs have been tested with images containing various defects such as crack, pothole, and spalling.

Key words: Gaussian Steerable Filter; Structural health survey; Structural damage; Computer vision; Software development.

Tóm tắt

Khảo sát định kỳ là một nhiệm vụ quan trọng để đảm bảo sự an toàn và khả năng làm việc của kết cấu. Nghiên cứu của chúng tôi phát triển một công cụ thị giác máy tính để phát hiện các khuyết tật trên bề mặt kết cấu dân dụng sử dụng các bộ lọc có hướng Gaussian. Công cụ này đã được chúng tôi phát triển với ngôn ngữ Visual C# .NET và xây dựng thành phần mềm để tăng tính ứng dụng của công cụ. Chương trình phần mềm đã được kiểm chứng với các mẫu ảnh chứa các khuyết tật trên bề mặt kết cấu bao gồm vết nứt, hố trên đường, và vết lở trên tường bê tông.

Từ khóa: Bộ Lọc Gabor, Khảo Sát Trạng Thái Kết Cấu; Hư Hỏng Kết Cấu; Thị Giác Máy Tính.

1. Introduction

The acceptable level of a structure's serviceability is crucial to ensure the safety of people. Accordingly, maintenance agencies need to perform periodically survey and collect the data regarding structural health. Accurate and timely recognition of structural have become an integral part of the building/infrastructure maintenance system. The reason is that early detection of structural

**Corresponding author*: Hoang Nhat Duc, Institute of Research and Development, Duy Tan University, Da Nang, 550000, Vietnam; Faculty of Civil Engineering, Duy Tan University, Da Nang, 550000, Vietnam;
Email: hoangnhatduc@duytan.edu.vn

defects can help to establish cost-effective rehabilitation methods and prevent reduction in service life of various structures [1-3].

Crack is a widely encountered form of surface degradation for buildings and asphalt pavements [4-7]. The detection of crack in pavement is crucial for road maintenance. It is because if cracks are recognized timely, the required cost of maintenance can be saved up to 80% [8]. Besides crack, various forms of structural damages can be found such as pothole for pavements and spall or bughole for concrete elements [9-14]. Thus, periodic structural health survey is mandatory to detect these forms of damages early to preclude accidents caused by structural degradation [15-20].

In recent years, computer vision has proved to be a capable tool for automatic structural heath survey. The computer-based approach has significantly enhanced the productivity and objectiveness of the structural surveying process. With such motivation, the current study aims at developing a software program based on computer vision to analyze digital images and highlight various forms of structural damages. Gaussian steerable filters are used to automatically analyze the image and detect edges representing damages on concrete surface including spall, crack, bughole, and pothole. The edges revealed by the Gaussian steerable filters can be subsequently employed for further damage categorization and measurement.

2. Gaussian Steerable Filters for image processing

The Gaussian Steerable Filter (GSF) [21, 22] is essentially an image enhancement technique that employs orientation-selective convolution kernels. As demonstrated in the previous works [23-25], this image enhancement technique is particularly useful to differentiate the crack patterns and the background texture of asphalt pavement. In addition to crack detections, GSF has been successfully employed in other tasks of the computer vision field [26-31].

It is noted that in the GSF algorithm, a linear combination of Gaussian second derivatives is used as a basic filter. For an image $I(x,y)$, a 2-D Gaussian at a certain pixel coordination is expressed as follows:

$$G(x,y,\sigma)=\frac{1}{2\pi\sigma^2}\exp[\frac{-(x^2+y^2)}{2\sigma^2}] \quad (1)$$

where σ denotes a tunable parameter of the Gaussian function variance.

The first order derivatives used to compute the filters at 0^o and 90^o are given by [22, 32]:

$$G_0=\frac{\partial G(x,y,\sigma)}{\partial x}=-\frac{x}{2\pi\sigma^4}\exp[\frac{-(x^2+y^2)}{2\sigma^2}] \quad (2)$$

$$G_{90}=\frac{\partial G(x,y,\sigma)}{\partial y}=-\frac{y}{2\pi\sigma^4}\exp[\frac{-(x^2+y^2)}{2\sigma^2}] \quad (3)$$

A filter at an arbitrary orientation β is given by [22]:

$$G_\beta=\cos(\beta)\times G_0+\sin(\beta)\times G_{90} \quad (4)$$

It is worth noticing that when the value of the Gaussian function variance (r) is fixed, the final filter response is a combined result of GSF with a set of orientation θ. The value of θ is selected from a set of angles such as $\{0,\frac{\pi}{4},\frac{2\pi}{4},\frac{3\pi}{4}\pi\}$ and $\{0,\frac{\pi}{6},\frac{2\pi}{6},\frac{3\pi}{6},\frac{4\pi}{6},\frac{5\pi}{6},\pi\}$.

The final SF response at the pixel location of (x,y) in the image I is computed as follows:

$$R(x,y)=F(x,y,\sigma,\beta)*I(x,y) \quad (5)$$

where '*' is the convolution operator.

3. Applications of the newly developed program

The performance of the newly developed software program based on GSF used for structural damage detection is demonstrated in

four categories of defects. The image samples have been collected by the Cannon EOS M10 (CMOS 18.0 MP) and Nikon D5100. The size of an image sample is 128x128 pixels. The images processed by GSF are demonstrated in Fig. 1. As can be seen from the figure, the integrated computer vision model has successfully highlighted the edges caused by damages in the surfaces of various structures: (a) concrete surface with crack, (b) asphalt pavement with crack, (c) wall with spalling, (d) asphalt pavement with a pothole, and (e) concrete column with a bughole.

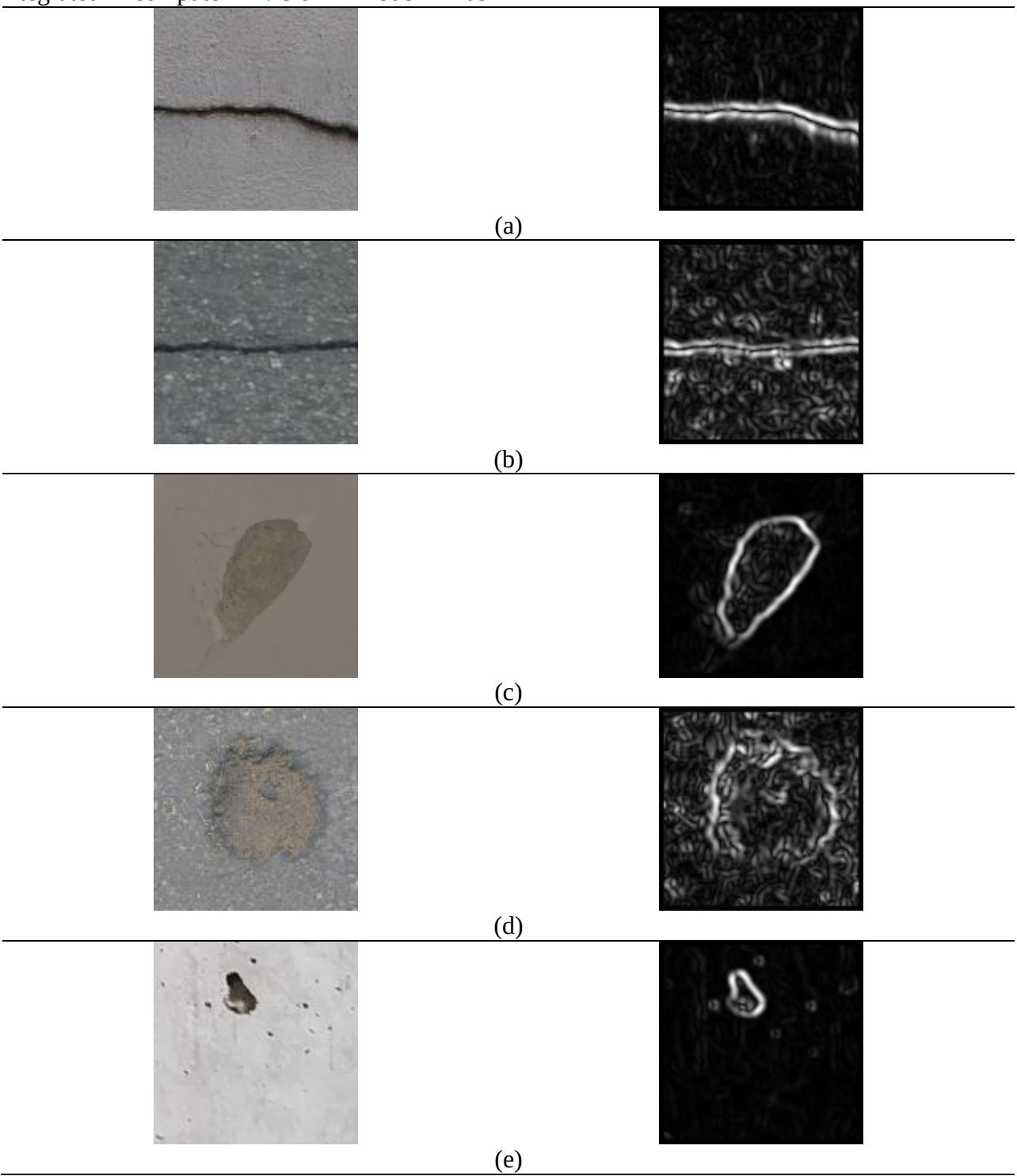

Fig. 1 Image analyses with images containing: (a) wall crack, (b) pavement crack, (c) spall in wall surface, (d) pavement pothole, and (e) concrete bughole

4. Concluding Remarks

Periodic survey of structural heath is important in building or infrastructure maintenance. To improve the productivity of this process, this work has developed a computer vision model based on the applications of the GSF to detect structural defects. Experiments show that the GSF based approach can effectively identify edge features caused by various types of distress. To facilitate the application of this model, a software program has been constructed. The capability of the newly developed program has been tested with five cases including the detections of crack, spalling, pothole, and bughole objects.

References

[1] N.-D. Hoang and Q.-L. Nguyen, "A novel method for asphalt pavement crack classification based on image processing and machine learning," *Engineering with Computers*, April 18 2018.

[2] N.-D. Hoang, "Classification of Asphalt Pavement Cracks Using Laplacian Pyramid-Based Image Processing and a Hybrid Computational Approach," *Computational Intelligence and Neuroscience*, vol. 2018, p. 16, 2018.

[3] Y. Liu and J. K. W. Yeoh, "Automated crack pattern recognition from images for condition assessment of concrete structures," *Automation in Construction*, vol. 128, p. 103765, 2021/08/01/ 2021.

[4] M. Gavilán, D. Balcones, O. Marcos, D. F. Llorca, M. A. Sotelo, I. Parra, *et al.*, "Adaptive Road Crack Detection System by Pavement Classification," *Sensors*, vol. 11, p. 9628, 2011.

[5] N.-D. Hoang, "Detection of Surface Crack in Building Structures Using Image Processing Technique with an Improved Otsu Method for Image Thresholding," *Advances in Civil Engineering*, vol. 2018, p. 10, 2018.

[6] N.-D. Hoang, Q.-L. Nguyen, and V.-D. Tran, "Automatic recognition of asphalt pavement cracks using metaheuristic optimized edge detection algorithms and convolution neural network," *Automation in Construction*, vol. 94, pp. 203-213, 2018/10/01/ 2018.

[7] Q. Chen, Y. Huang, H. Sun, and W. Huang, "Pavement crack detection using hessian structure propagation," *Advanced Engineering Informatics*, vol. 49, p. 101303, 2021/08/01/ 2021.

[8] Y. O. Ouma and M. Hahn, "Wavelet-morphology based detection of incipient linear cracks in asphalt pavements from RGB camera imagery and classification using circular Radon transform," *Advanced Engineering Informatics*, vol. 30, pp. 481-499, 2016/08/01/ 2016.

[9] N.-D. Hoang, "Image Processing-Based Spall Object Detection Using Gabor Filter, Texture Analysis, and Adaptive Moment Estimation (Adam) Optimized Logistic Regression Models," *Advances in Civil Engineering*, vol. 2020, p. 8829715, 2020/11/30 2020.

[10] N.-D. Hoang, Q.-L. Nguyen, and X.-L. Tran, "Automatic Detection of Concrete Spalling Using Piecewise Linear Stochastic Gradient Descent Logistic Regression and Image Texture Analysis," *Complexity*, vol. 2019, p. 14, 2019.

[11] N.-D. Hoang and Q.-L. Nguyen, "Metaheuristic Optimized Edge Detection for Recognition of Concrete Wall Cracks: A Comparative Study on the Performances of Roberts, Prewitt, Canny, and Sobel Algorithms," *Advances in Civil Engineering*, vol. 2018, p. 16, 2018.

[12] B. Liu and T. Yang, "Image analysis for detection of bugholes on concrete surface," *Construction and Building Materials*, vol. 137, pp. 432-440, 2017/04/15/ 2017.

[13] G. Yao, F. Wei, Y. Yang, and Y. Sun, "Deep-Learning-Based Bughole Detection for Concrete Surface Image," *Advances in Civil Engineering*, vol. 2019, p. 12, 2019.

[14] N.-D. Hoang, "An Artificial Intelligence Method for Asphalt Pavement Pothole Detection Using Least Squares Support Vector Machine and Neural Network with Steerable Filter-Based Feature Extraction," *Advances in Civil Engineering*, pp. 1-12, 2018.

[15] N.-D. Hoang, "Image processing based automatic recognition of asphalt pavement patch using a metaheuristic optimized machine learning approach," *Advanced Engineering Informatics*, vol. 40, pp. 110-120, 2019/04/01/ 2019.

[16] C. Koch, S. G. Paal, A. Rashidi, Z. Zhu, M. König, and I. Brilakis, "Achievements and Challenges in Machine Vision-Based Inspection of Large Concrete Structures," *Advances in Structural Engineering*, vol. 17, pp. 303-318, 2014.

[17] S. C. Radopoulou, I. Brilakis, K. Doycheva, and C. Koch, "A Framework for Automated Pavement Condition Monitoring," in *Construction Research Congress 2016*, ed, 2016.

[18] N.-D. Hoang and V.-D. Tran, "Image Processing-Based Detection of Pipe Corrosion Using Texture Analysis and Metaheuristic-Optimized Machine Learning Approach," *Computational Intelligence and Neuroscience*, vol. 2019, p. 13, 2019.

[19] Y.-S. Yang, C.-l. Wu, T. T. C. Hsu, H.-C. Yang, H.-J. Lu, and C.-C. Chang, "Image analysis method for

crack distribution and width estimation for reinforced concrete structures," *Automation in Construction*, vol. 91, pp. 120-132, 2018/07/01/ 2018.

[20] H. N. Nguyen, T. Y. Nguyen, and D. L. Pham, "Automatic Measurement of Concrete Crack Width in 2D Multiple-phase Images for Building Safety Evaluation," Cham, 2018, pp. 638-648.

[21] W. T. Freeman and E. H. Adelson, "Steerable filters for early vision, image analysis, and wavelet decomposition," in *[1990] Proceedings Third International Conference on Computer Vision*, 1990, pp. 406-415.

[22] W. T. Freeman and E. H. Adelson, "The design and use of steerable filters," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 13, pp. 891-906, 1991.

[23] H. Chen, H. Zhao, D. Han, and K. Liu, "Accurate and robust crack detection using steerable evidence filtering in electroluminescence images of solar cells," *Optics and Lasers in Engineering*, vol. 118, pp. 22-33, 2019/07/01/ 2019.

[24] N.-D. Hoang, "Image Processing-Based Recognition of Wall Defects Using Machine Learning Approaches and Steerable Filters," *Computational Intelligence and Neuroscience*, vol. 2018, p. 18, 2018.

[25] N.-D. Hoang and Q.-L. Nguyen, "Fast Local Laplacian-Based Steerable and Sobel Filters Integrated with Adaptive Boosting Classification Tree for Automatic Recognition of Asphalt Pavement Cracks," *Advances in Civil Engineering*, vol. 2018, p. 17, 2018.

[26] M. Jacob and M. Unser, "Design of steerable filters for feature detection using canny-like criteria," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 26, pp. 1007-1019, 2004.

[27] S. Li, Y. Cao, and H. Cai, "Automatic Pavement-Crack Detection and Segmentation Based on Steerable Matched Filtering and an Active Contour Model," *Journal of Computing in Civil Engineering*, vol. 31, p. 04017045, 2017.

[28] J. Liang, X. Gu, and Y. Chen, "Fast and robust pavement crack distress segmentation utilizing steerable filtering and local order energy," *Construction and Building Materials*, vol. 262, p. 120084, 2020/11/30/ 2020.

[29] H. Mahersia and K. Hamrouni, "Using multiple steerable filters and Bayesian regularization for facial expression recognition," *Engineering Applications of Artificial Intelligence*, vol. 38, pp. 190-202, 2015/02/01/ 2015.

[30] N.-D. Hoang, Q.-L. Nguyen, and D. T. Bui, "Image Processing-Based Classification of Asphalt Pavement Cracks Using Support Vector Machine Optimized by Artificial Bee Colony," *Journal of Computing in Civil Engineering*, vol. 32, p. 04018037, 2018.

[31] N.-D. Hoang and Q.-L. Nguyen, "Automatic Recognition of Asphalt Pavement Cracks Based on Image Processing and Machine Learning Approaches: A Comparative Study on Classifier Performance," *Mathematical Problems in Engineering*, vol. 2018, p. 16, 2018.

[32] TUM, "1D and 2D Gaussian Derivatives," *Technische Universität München, Lehrstuhl für Computer Aided Medical Procedures & Augmented Reality* <http://campar.in.tum.de/Chair/HaukeHeibelGaussianDerivatives>, 2021.