Conference Proceedings 4th ICTB (2022)
https://doi.org/10.24451/sxp0-fx66

ICTB 2021 PLUS
4th International Conference on Timber Bridges
Biel/Bienne, Switzerland, 9 -12 May 2022

Defect Identification Coupled with Grayscale Image Enhancement Technology

Junwon Seo[1], Euiseok Jeong, James Wacker

Abstract

The goal of this study was to improve the visibility of defects within inspection images obtained by drones using image enhancement technologies. In recent years, drones have been applied to bridge inspections as reported by several studies as a result of the drones' abilities such as providing improved accessibility along with high image resolution. However, poor-quality inspection images frequently hamper the process of efficient defect identification and quantification with low visibility caused by brightness and/or contrast inconsistencies. To resolve such issues, a grayscale image enhancement algorithm in MATLAB and image property adjustment were considered for this study. The visibility of representative images, collected from a drone-aided inspection on an existing timber slab bridge located in the state of Minnesota in the United States, was improved through the use of an Adaptive Histogram Equalization algorithm available within MATLAB and image property adjustment algorithm. To evaluate the accuracy of the algorithms with the drone inspection images, defect area quantification for the weathering identified during the inspection was conducted using an unfiltered drone image (0.097 m^2), grayscale image (0.078 m^2), the enhanced image visibility (0.118 m^2) with the adaptive histogram equalization algorithm, and the filtered image (0.085 m^2) using image property adjust algorithm. From this work, it was concluded that the adaptive histogram equalization algorithm applied to the drone imagery is capable of improving the image visibility to better quantify the defect areas.

1 Introduction

According to America's Infrastructure report cards [1,2], the grades of bridges in the United States (U.S.) were down from C+ to C between 2017 and 2021. 267,316 U.S. bridges were under the fair condition in 2017, and the number of fair bridges gradually increased to 291,339 in 2019, while the number of bridges in good condition decreased from 288,126 in 2017 to 279,582 in 2019. In particular, the number of bridges in fair condition has exceeded the number of bridges in good condition in 2019, the first time since 2009 [2]. Furthermore, approximately 260,000 bridges (42% of all U.S. bridges) are evaluated as deteriorating bridges, which have been in service for 50 years old or more. With these concerns, bridge maintenance will gain more interest from bridge engineers and owners. For appropriate bridge maintenance, periodic bridge inspections with high accuracy and cost-efficiency shall be one of the most important priorities. As the periodic bridge inspections, conventional bridge inspections with direct measurement have been conducted to date but are increasingly a higher cost and riskier work task. For example, when critical defects to the bridge exist at an inaccessible location by inspectors, the conventional inspections shall be carried out through rope access or by use of specialized vehicles such as under-bridge inspection vehicles, e.g., snooper trucks or boom lift trucks. During these inspections, some accidents have occurred with rope access [20] or specialized vehicles [3,12]. The risk of these accidents can be prevented or greatly reduced with drone-aided bridge inspections. With the merits of drone-aided bridge inspections, the cases of drone use in bridge inspections by the U.S. State Departments of Transportation (DOTs) increased from 6% to 21% [13]. Many studies on bridge inspections using drones considered that such bridge inspection approaches can be a proper alternative to conventional inspections [14,15,24].

With drones, inspectors can acquire inspection images and identify defects to generate results of the bridge inspections. For such an endeavor, the quality of the drone inspection images is most critical to bridge evaluation. However, these inspection images are significantly influenced by the surrounding environments of the bridges. For instance, defects on bridges are not able to be identified in images with inadequate light exposure, such as images taken underneath the bridge having low light exposure. To improve visibility of low-quality images, inspectors can consider image processing methods, e.g., edge detection [4], k-means clustering [5], Grayscale image processing [16,19], and brightness-contrast-sharpness adjustment [17,25]. Among them, grayscale image processing is efficiently capable of converting an existing color image to

[1] Junwon Seo, Associate Professor with Tenure and Chairman of ASCE Timber Bridges Committee, South Dakota State University, United States, Junwon.Seo@sdstate.edu

grayscale and adjusting the pixel's contrasts to enhance the visibility of inspection images. In a past study [16], grayscale image processing was applied to bridge inspection images obtained by drones. It was found that the quality of drone inspection images was improved with the grayscale image processing and the boundaries of defects due to efflorescence, water leakage, discoloration, and so on were detected effortlessly. Specifically, the clear boundaries of defects (i.e., water leakage and efflorescence) were identified through grayscale image-based adaptive histogram equalization [16]. The adaptive histogram equalization [19] was ordinarily used to separate images into small regions, to amend contrast for each small region to increase visibility, and to combine the small regions into the image for the prevention of undesired boundaries in the image.

The goal of this study is to improve the accuracy and efficiency of defect identification and quantification using the images obtained through drone-aided bridge inspections. To achieve this goal, grayscale image processing technology was implemented into images acquired from drone-aided inspections for an in-service bridge in the U.S. This paper consists of three sections, including this section, methodology, and results and discussions.

2 Methodology

In recent years, drone technology has gained traction in several studies [6–8, 14–17, 21–29] as a supplementary bridge inspection approach. Despite a burgeoning interest in using drones in bridge inspections, some issues have arisen related to the image quality during drone-aided inspections. To address this image quality issue, the grayscale image enhancement algorithm in MATLAB [18] and image property adjustment technology [17, 25] were applied. For evaluation of the algorithms, DJI Matrice 210 inspected an existing timber slab bridge located in Minnesota on August 20, 2019. The inspected bridge was built in 1987, and the type of bridge is a three-span, timber slab bridge having a structure length of 31.1 m and a deck width of 10.36 m. According to the NBI condition rating system, the deck, superstructure, and substructure were recently evaluated to be in good condition exhibiting minor defects but with no structural issues [9–11]. The bridge inspection was performed on the east side, west side, and underneath the deck, as shown in Figure 1a. A representative defect due to weathering observed on the east side of the bridge can be depicted in Figure 1b. Although the defect on the bridge element is observed using inspection images obtained from the drone, the defect measurement may be impeded due to unclear boundaries with some type of deterioration such as weathering. To resolve this issue, two image processing technologies, grayscale image enhancement technologies available in MATLAB [18, 19] and image property adjustment technology [17, 25], were considered. Adaptive histogram equalization technology among the grayscale image enhancement technologies adjusts the contrast on specific small regions, known as tiles, in the image. During this processing, the histogram of the tile approaches a specified contrast histogram. In the last step of processing, bilinear interpolation is performed on neighboring tiles to remove the tile boundaries. On the other hand, the image property adjustment technology can improve the visibility of inspection images with adjustment of various image properties including brightness, contrast, and sharpness.

(a) (b)

Figure 1: Bridge inspection: (a) drone-aided bridge inspection and (b) inspection images captured by DJI Matrice 210.

3 Results and discussions

The results of two technology applications, including image property adjustment technology and grayscale image enhancement technology, will be discussed in the following sections. To compare the results, the technologies amend and improve the same raw inspection image (refer to Figure 1b).

3.1 Application of grayscale image enhancement technology

The proposed image enhancement methodology was applied to the drone captured image shown in Figure 1b. In this methodology, the original color drone image (refer to Figure 1b) is converted to a grayscale image as depicted in Figure 2a and the corresponding contrast histogram as shown in Figure 2b. In Figure 2a, the weathering area marked yellow boundaries is not visibly observed. Note, the dark areas marked by a white dashed box are not detected due to low visibility. The adaptive histogram equalization algorithm was employed to enhance the visibility of the image as depicted in Figure 2c and relevant contrast histogram (see Figure 2d). In a comparison of histograms, Figure 2d shows the uniform distribution compared to Figure 2b. With a contrast adjustment, the weathering area changed and it can be observed underneath the deck compared to the grayscale image (refer to Figure 2a) and original image (see Figure 1b). The measured weathering areas are 0.097 m² for Figure 1b (original color drone image), 0.078 m² for Figure 2a (converted grayscale image), and 0.118 m² for Figure 2d (application of grayscale image enhancement). It was revealed that the adaptive histogram equalization can improve the visibility of images to more efficiently identify the defects through this methodology.

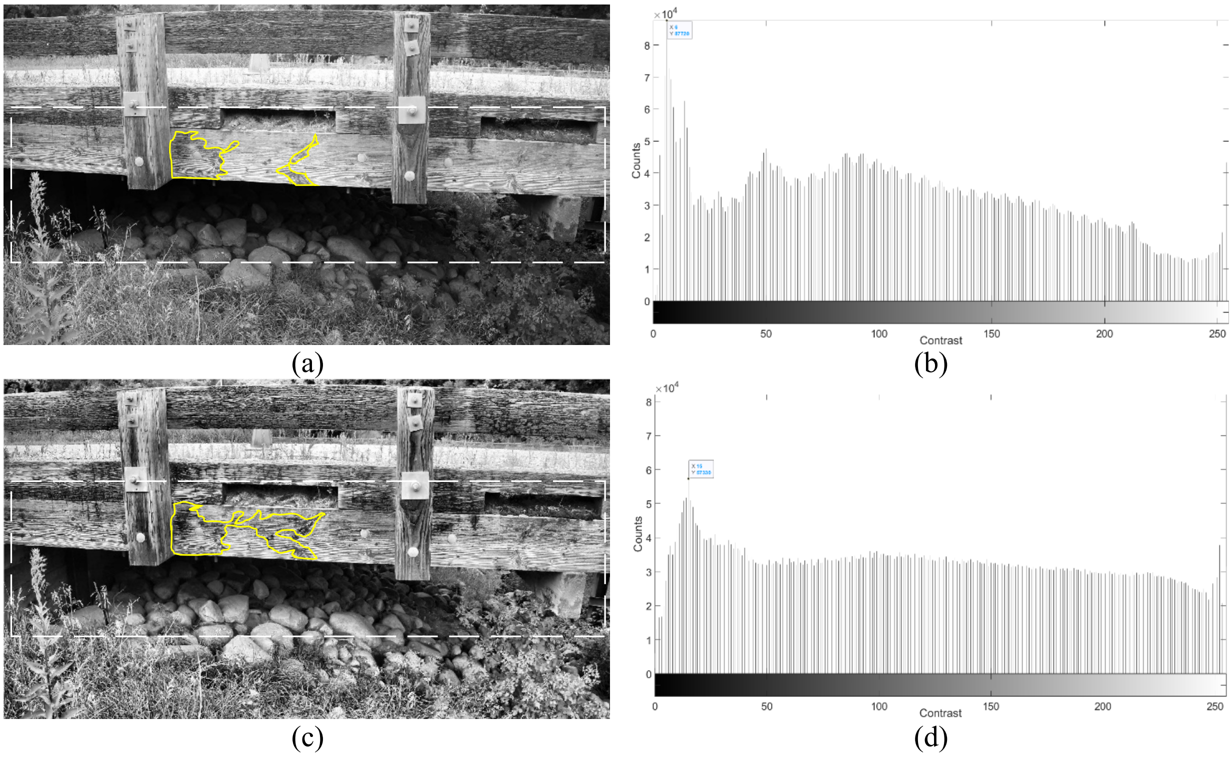

Figure 2: Grayscale image enhancement applications using inspection image (Figure 1b): (a) grayscale image conversion; (b) histogram of Figure 2a; (c) adaptive histogram equalization algorithm application; and (d) histogram of Figure 2c.

3.2 Application of image property adjustment technology

To improve the visibility of the inspection image (see Figure 1b), image property adjustment technology is applied to this image. This technology amends the image properties (brightness, contrast, and sharpness) as shown in Figure 3. All properties can be adjusted from -100% to 100% and the default value of each property is 0%. The negative values of properties indicate darkness, low contrast, and blurriness in the adjustment of brightness, contrast, and sharpness, respectively. The inspection image (Figure 1b) was adjusted with brightness -10%, contrast 30%, and sharpness 20% as depicted in Figure 3. The defects due to wearing on the side of the bridge are detected obviously as marked with red boundaries in Figure 2. The measured area of weathering is 0.085 m².

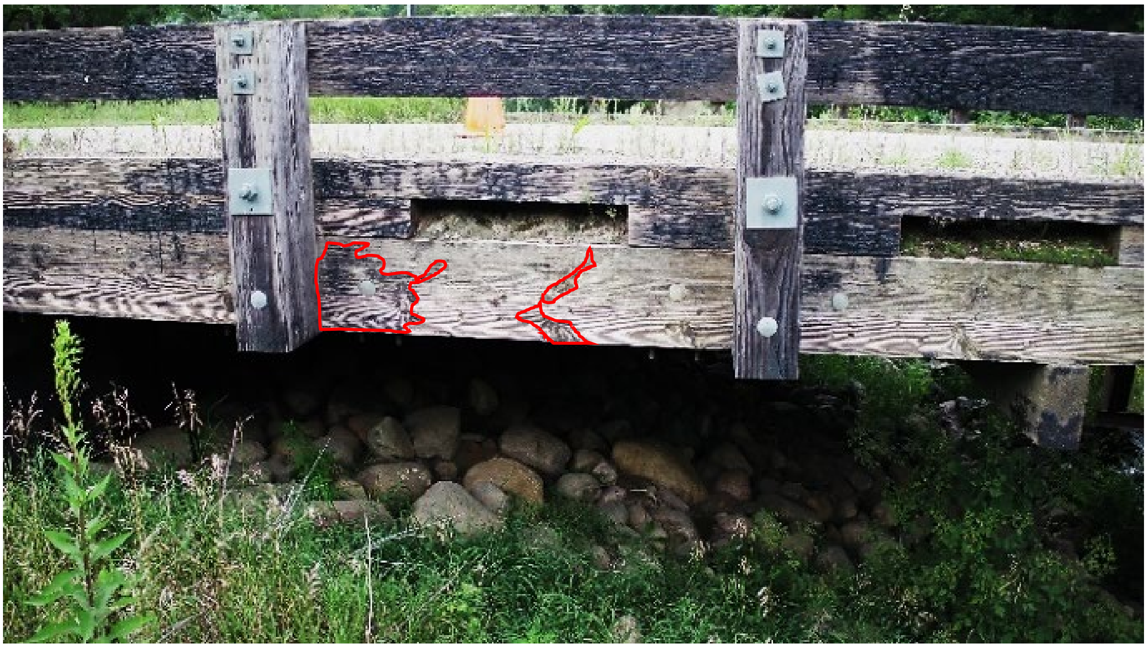

Figure 3. Image property adjustment application using inspection image (Figure 1b) adjusted with brightness -10%, contrast 30%, and sharpness 20%.

For this study, two image processing technologies, i.e., grayscale image enhancement and image property adjustment technologies, were applied in order to improve the visibility of the drone inspection images, which show representative defects due to weathering observed on the east side of the bridge. Although the visibility of the inspection images can be improved through the suggested image property adjustment technology, the improvement of the visibility of defect boundaries was limited. Compared to image property adjustment, the grayscale image enhancement technology was considered as an accurate and efficient methodology during the measurement of the defect having an area (i.e., weathering). Furthermore, additional areas of weathering on the side of the bridge (yellow boundaries in Figure 2c) were observed in the application image of grayscale enhancement technology, while this area was not identified through image property adjustment as depicted in Figure 3. Thus, for defect identification, the application of image property adjustment technology to inspection images can be recommended, whereas defect measurement will be more accurate and efficient through grayscale image enhancement technology.

Acknowledgment

Partial financial support for this research was provided by the United States Department of Agriculture (USDA) Forest Service–Forest Products Laboratory (FPL) through a cooperative research agreement (No. 18-JV-11111133-031). The assistance and cooperation of Lincoln County in Minnesota are gratefully acknowledged.

References

[1] American Society of Civil Engineers (ASCE) (2017) Infrastructure Report Card. American Society of Civil Engineers (ASCE), Washington, D.C., p. 110.

[2] American Society of Civil Engineers (ASCE) (2021) Report Card for Americas's Infrastructure. American Society of Civil Engineers (ASCE), Washington, D.C., p. 169.

[3] Atkinson, B. (2015) Snooper truck overturns on I-84 on-ramp, crushes bridge inspector in Connecticut. Equipment World.

[4] Canny, J. (1986) A Computational Approach to Edge Detection. IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-8(6), 679–98, Doi: 10.1109/TPAMI.1986.4767851.

[5] Chen, T.-W., Chen, Y.-L., Chien, S.-Y. (2008) Fast image segmentation based on K-Means clustering with histograms in HSV color space. 2008 IEEE 10th Workshop on Multimedia Signal Processing, pp. 322–5.

[6] Duque, L., Seo, J., Wacker, J.P. (2018) Timber Bridge Inspection Using UAV. Structures Congress 2018, Fort Worth, TX, pp. 186–96.

[7] Duque, L., Seo, J., Wacker, J.P. (2018) Synthesis of Unmanned Aerial Vehicle Applications for Infrastructures. Journal of Performance of Constructed Facilities 32(4), 04018046, Doi: 10.1061/(ASCE)CF.1943-5509.0001185.

[8] Duque, L., Seo, J., Wacker, J.P. (2018) Bridge Deterioration Quantification Protocol Using UAV. Journal of Bridge Engineering 23(10), 04018080, Doi: 10.1061/(ASCE)BE.1943-5592.0001289.

[9] Federal Highway Administration (FHWA) (1995) Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges. U.S. DOT FHWA, Washington, DC, p. 124.

[10] Federal Highway Administration (FHWA) (2012) Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges. U.S. DOT FHWA, Washington, DC, p. 124.

[11] Federal Highway Administration (FHWA) (2018) Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges. U.S. DOT FHWA, Washington, DC, p. 124.

[12] Grayson, W. (2015) Boom lift overturns, killing worker on Massachusetts jobsite. Equipment World.

[13] Jeong, E., Seo, J., Wacker, J.P. (2020) Literature Review and Technical Survey on Bridge Inspection Using Unmanned Aerial Vehicles. Journal of Performance of Constructed Facilities 34(6), 04020113, Doi: 10.1061/(ASCE)CF.1943-5509.0001519.

[14] Jeong, E., Seo, J., Wacker, J.P. (2020) New Bridge Inspection Approach with Joint UAV and DIC System. Structures Congress 2020, St. Louis, MO, pp. 349–59.

[15] Jeong, E., Seo, J., Wacker, J.P. (2020) Non-Contact Bridge Inspection and Damage Quantification Approach using UAS. US-Korea Conference (UKC) 2020 – Virtual Event, Korean-American Scientists and Engineers Association (KSEA).

[16] Jeong, E., Seo, J., Wacker, J.P. (2021) Grayscale Drone Inspection Image Enhancement Framework for Advanced Bridge Defect Measurement. Transportation Research Record 2675(8), 603–12, Doi: 10.1177/0361198121999605.

[17] Jeong, E., Seo, J., Wacker, J.P. (2022) UAV-aided bridge inspection protocol through machine learning with improved visibility images. Expert Systems with Applications 197, 116791, Doi: 10.1016/j.eswa.2022.116791.

[18] MATLAB (2020) MATLAB version 9.9.0. 1538559 (R2020b Update 3). The MathWorks Inc., Natick, Massachusetts.

[19] MATLAB & Simulink (2020) Enhance Grayscale Images. https://www.mathworks.com/help/images/contrast-enhancement-techniques.html. [accessed July 24, 2020].

[20] Robbins, C.H. (2017) Work & Safety analysis 2017. Industrial Rope Access Trade Association (IRATA) International, Ashford, UK, p. 81.

[21] Seo, J., Duque, L., Wacker, J.P. (2018) Field Application of UAS-Based Bridge Inspection. Transportation Research Record: Journal of the Transportation Research Board, 036119811878082, Doi: 10.1177/0361198118780825.

[22] Seo, J., Duque, L., Wacker, J.P. (2018) Drone-enabled bridge inspection methodology and application. Automation in Construction 94, 112–26, Doi: 10.1016/j.autcon.2018.06.006.

[23] Seo, J., Duque, L., Wacker, J.P. (2019) Glued-Laminated Timber Arch Bridge Inspection Using UAV. Computing in Civil Engineering 2019, pp. 336–42.

[24] Seo, J., Jeong, E., Wacker, J.P. (2020) Drone-Aided Bridge Inspection Coupled with Image Quality Improvement Processing Technique. NDE/NDT Structural Materials Technology for Highways and Bridges 2020, Online Only, OH.

[25] Seo, J., Jeong, E., Wacker, J.P. (2021) Visual Bridge Damage Measurement Using Drone-Captured Image Quality Optimization. In: Rizzo, P., Milazzo, A., (Eds.), European Workshop on Structural Health Monitoring, Springer International Publishing, Cham, pp. 503–13.

[26] Seo, J., Jeong, E., Wacker, J.P. (2021) Visible Damage Examination of Concrete Bridge Decking using UAS. ACI Virtual Concrete Convention, American Concrete Institue (ACI).

[27] Seo, J., Jeong, E., Wacker, J.P. (2021) Advanced Defect Identification and Quantification Using Grayscale UAS Inspection Images. US-Korea Conference (UKC) 2021, Korean-American Scientists and Engineers Association (KSEA), Los Angeles area, CA.

[28] Seo, J., Wacker, J.P., Duque, L. (2018) Evaluating the use of drones for timber bridge inspection. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, p. 145.

[29] Seo, J., Wacker, J.P., Jeong, E. (2022) Evaluation of Unmanned Aircraft Systems as a Bridge Inspection Tool – Phase II. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI, In Press.