A Concrete Bridge Crack Size Measurement Procedure based on Unmanned Aerial Vehicle and Image Registration

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ABSTRACT: As cracks play a vital role for the durability of concrete bridges, crack detection becomes a necessity for concrete bridge inspection. However, the widely-used visual inspection for the crack detection is not only unsafe for inspectors, but also time and labor consuming. Thus, in this research, we propose a workflow that utilizes high-resolution digital cameras on unmanned aerial vehicles (UAVs) to measure concrete crack sizes. To be specific, we first use long-range images to establish the absolute coordinate system with control points and then register long-range and close-up images with the SIFT (Scale-Invariant Feature Transform). In this case, when measuring crack sizes on close-up images, we can derive the absolute size of each crack. Finally, crack sizes are measured manually on close-up images. An experiment was conducted on a concrete prototype in a laboratory. Comparing to the in-situ measurements from two surveyors, the proposed solution can measure crack lengths with 3.97mm root mean square error (RMSE), -0.93mm mean absolute error (MAE) and 3.58% mean relative error (MRE) and measure crack widths with 0.33mm RMSE, -0.0055mm MAE and 20.29% MRE.

Overall, there are four main contributions in this preliminary research. (1) We propose a safe and efficient concrete crack inspection method by using UAVs. (2) We present a camera calibration workflow for digital zoom cameras to reduce errors caused by lens distortions. (3) For the long-range and close-up image registration, we demonstrate that the SIFT is an image matching method that can accommodate scale and orientation changes. (4) We identify potential issues for crack measurement that could help lead to future research improvements.

1. Introduction

Bridges suffer from natural disasters and the accumulation of every day traffic flow. Therefore, regular bridge inspections are necessary. Since cracks significantly affect the durability of bridges, crack inspection has been listed as an important procedure to evaluate the damage level of bridges (Ministry of Transportation and Communications in Taiwan, 2017).

In the past decades, well-trained inspectors need to climb on ladders and measure cracks by crack scalars. Since cracks can be everywhere over a bridge and some regions are difficult for inspectors to reach, inspectors usually need to use scaffoldings or robotic arms. However, considering the security of inspectors and the high cost of scaffoldings and robotic arms (Lovelace, 2015), the unmanned aerial vehicle (UAV) technique could be a feasible alternative for bridge inspections.

Applying UAVs on bridge inspections can reduce the high expense from traditional inspections and easily access more regions of a bridge. Thus, the main objectives of this research is to construct the absolute coordinate system of cracks and measure their sizes and implement a concrete bridge crack inspection method by processing the high-resolution images from UAVs.

2. Methodology

2.1 Instrument

This research applies the Parrot Anafi, as shown in Figure 1. This UAV not only has a high-resolution camera, but also can rotate the camera to face the top side in order to detect cracks under the bridge deck.

(a) UAV (b) controller

Figure 1. Parrot Anafi and its controller.

2.2 Workflow

As shown in Figure 2., since the UAV mounts a non-metric camera, we need to apply camera calibration in order to reduce the displacements of principal point and lens distortions. Second, we take close-range and long-range images on cracks and the bridge. The absolute coordinate system is constructed through control points in long range images. Afterwards, we register close-range images to long range images to obtain the absolute coordinates of each crack. Finally, we measure the crack sizes manually on close-range images and validate with reference sizes measured by surveyors.

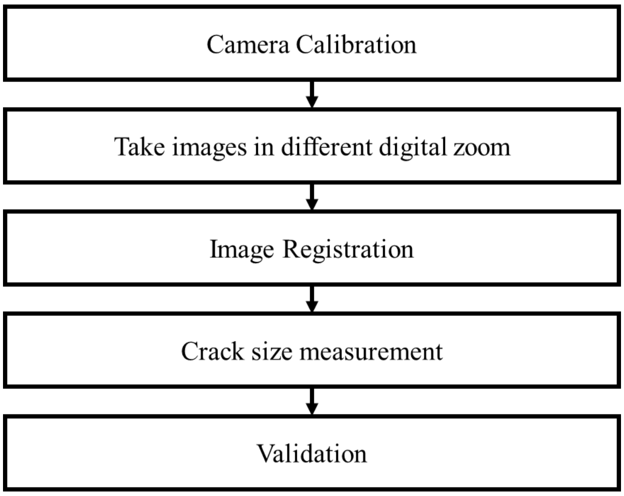


Figure 2. The overall workflow.

2.3 Camera Calibration

The high-resolution non-metric prime lens camera mounted on the UAV changes image scopes with digital zooms, which would not change the actual focal lengths. Thus, in our research, we retrieve internal orientation parameters through iWitnessPRO^{TM} from the 1x image and validate if the images in other digital zooms can be calibrated by the same calibration parameters. The workflow is shown in Figure 3.

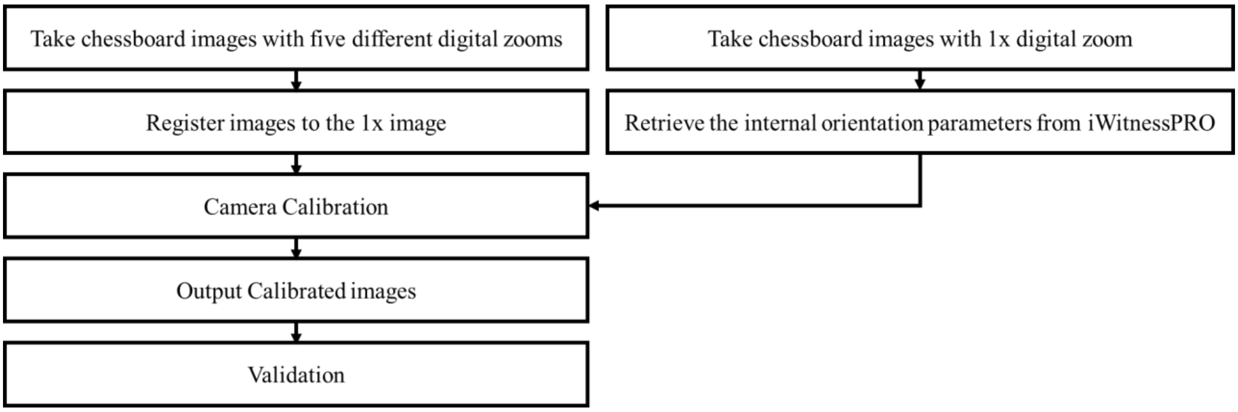


Figure 3. The workflow for camera calibration.

iWitnessPRO™ use ten parameters for image coordinate correction functions. Besides 3 internal orientation parameters, it also includes 7 additional parameters to represent lens distortions. The calibration parameters, as the functions shows below, include principal points, the displacements of principal points (xp, yp), radial distortions K1, K2, K3, exterior distortions P1, P2, and affine distortions B1, B2. (Fraser, 1997)

$$\bar{x} = x - xp \tag{1}$$

$$\bar{y} = y - yp \tag{2}$$

$$\mathrm{r} = \sqrt{\bar{x}^2 + \bar{y}^2} \tag{3}$$

$$\mathrm{dr} = K_1 r^3 + K_2 r^5 + \ K_3 r^7 \tag{4}$$

$$x_c = \bar{x} + \bar{x}\frac{dr}{r} + P_1(r^2 + 2\bar{x}^2) + 2P_2\bar{x}\bar{y} + B_1\bar{x} + B_2\bar{y} \tag{5}$$

$$y_c = \bar{y} + \bar{y}\frac{dr}{r} + P_2(r^2 + 2\bar{y}^2) + 2P_1\bar{x}\bar{y} \tag{6}$$

2.4 Imaging taking

In our preliminary experiment, we set a concrete beam on a horizontal table, and take images of its cracks to develop the methods. In the future work, we will apply the experiment on a real concrete bridge. Thus, the conditions of taking images of real concrete bridges should be considered in order to simulate the real situation as possible. Furthermore, to build an absolute coordinate system to measure crack widths, image registrations are needed. Close-range and long-range images are taken. For long-range images, there should be at least three control points included to set the absolute coordinates, as shown in Figure 4(a). On the other hand, in order to clearly identify edges of cracks and precisely measure widths of cracks, close-range images are applied, as shown in Figure 4(b).

(a) The long-range image includes control points (triangles).

(b)The close-range image with clear crack characteristics.

Figure 4. The long-range (a) and the close-range (b) images of the concrete beam.

2.5 Image registration

Long-range and close-range concrete crack images are taken in this research, and retrieve absolute coordinates from the control points in long-range images. Afterwards, we register the close-range images to long-range images through SIFT (Scale-Invariant Feature Transform), a method which can accommodate scale and orientation differences, in order to register the close-range images to the absolute coordinate system in long-range images to locate the absolute positions of each crack.

SIFT is a method published by Lowe in 2004. First, through repeating the Laplace Gaussian transform and calculating the difference of Gaussian among images, SIFT builds the image pyramid, which the number of layers is decided by the image scale to reduce the obscurity of images. Images on every layer will be reduced into one-fourth to ensure features can be found in every scale. Moreover, extremum points will be found from every layer in the scale space of Gaussian difference, which can be seen as features to process the image registration in different scales.

2.6 Crack measurement

In this preliminary research, we utilize ERDAS IMAGINE 2013 image processing software to measure crack lengths and widths. We first identify the number of cracks and their locations in the images. Afterwards, we calculate the pixel sizes of cracks in order to estimate crack lengths by the number of pixels included in a crack segment. Meanwhile, we define the normal direction of a crack segmentation as the width of a crack that is measured manually.

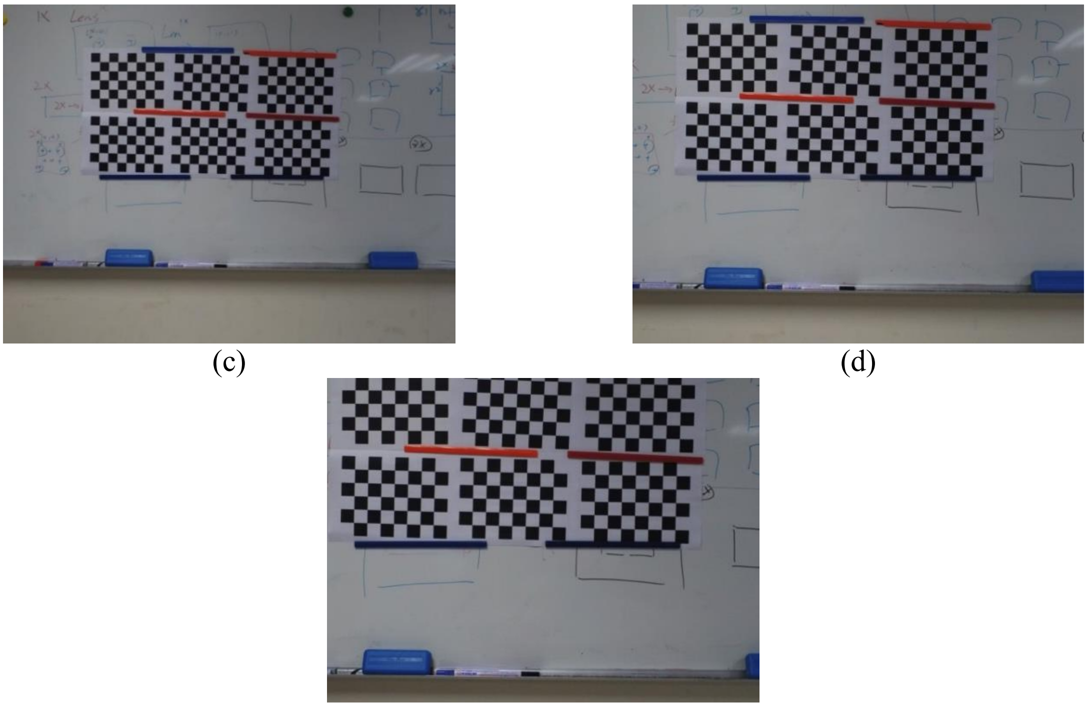
3. Preliminary Results

3.1 Camera calibration

According to the data sheet from Parrot, Parrot Anafi carries a digital zoom camera that only adjusts the image scopes without changing the focal length. According to the theory of camera calibration published by Fraser in 1997, a digital zoom camera only contains one set of calibration parameters. Thus, in this step, we validate the possibility of utilizing the internal parameters retrieved from the 1x image on other zooms.

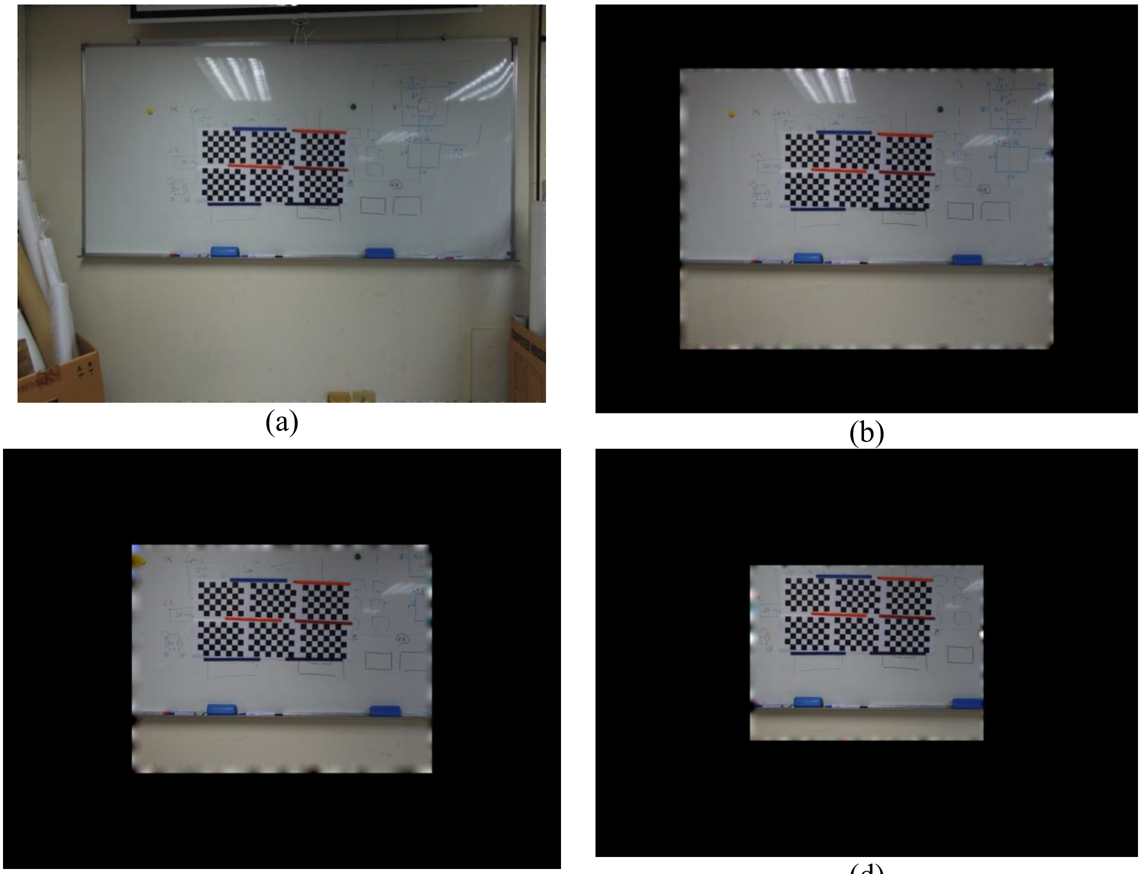
In this research, we take images with five different zooms (i.e., 1, 1.5, 2, 2.5, 3), as shown in Figure5. We build the coordinate transform functions between 1x image and the other 4 digital zoom images. According to the experiment, the other 4 digital zoom images only retain a subregion and resample the images in order to turn it into closer-range images. Afterwards, we transform the other 4 digital zoom images to 1x images through the coordinate transform functions we get from previous step, and we calibrate the images with the internal parameters retrieved from the 1x image. The calibrated results are shown in Figure 6. In order to validate if the procedure is feasible to calibrate digital zoom images, we set 36 check points, as shown in Figure 7. As the experiment result shows, each conjugate points have at most 1.12-pixel distortions, and 0.61-pixel root mean square error, which only cause the error around 0.5mm toward object space. Thus, we believe it is possible to utilize this workflow for the calibration of crack images.

(a) (b)

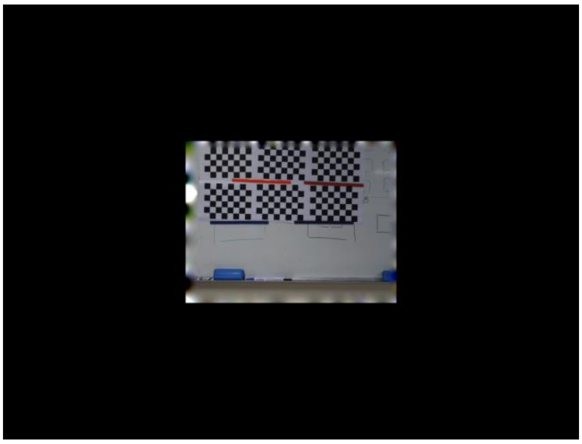

(c) (d)

(e)

Figure 5. (a)1x, (b)1.5x, (c)2x, (d)2.5x, (e)3x chessboard images.


(a) (b)

(c) (d)



(e)

Figure 6. (a)1x, (b)1.5x, (c)2x, (d)2.5x, (e)3x calibrated images.

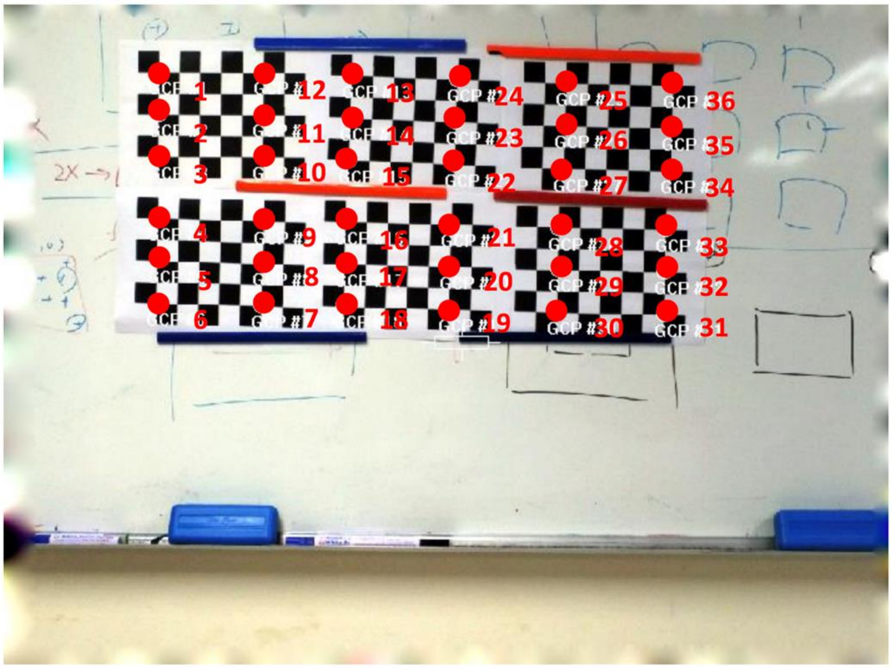


Figure 7. 36 check points.

3.2 Image registration

In order to obtain images covering control points for constructing the absolute coordinate system and clear images with cracks, both close-range and long-range images should be taken. Furthermore, it is better to remain a safe distance between the UAV and the bridge in order to avoid possible crash. To simulate the real scenario, this experiment intentionally remains at least one-meter distance to take images.

In a real scenario, we may utilize larger digital zooms to obtain high-resolution images. Thus, in this experiment, we examine three situations: (1) Based on five individual digital zooms, register their own long-range and close-up images. (2) Register a 1x long-range image with close-up images in other digital zooms, as shown in Figure 8 to 11. (3) Register the 2x and 3x close-up images with the 1x long-range image taken from a side-view, as shown in Figure 12 and 13. The experiment results show that SIFT can successfully find some matched points in all three situations. In addition, the situation (2) can find more conjugate points that are uniformly distributed. Therefore, images satisfying the situation (2) is preferable in our future work for the image registration. Furthermore, the situation (3) shows that SIFT is able to accommodate differences in camera orientations, which means that the image registration can still be achieved if side-viewing images are unavoidable.

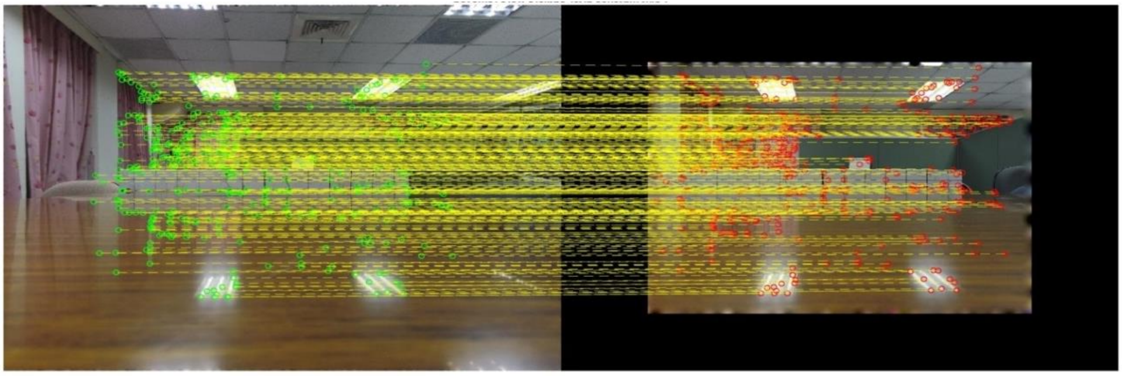


Figure 8. Image registration of 1.5x and 1x images.

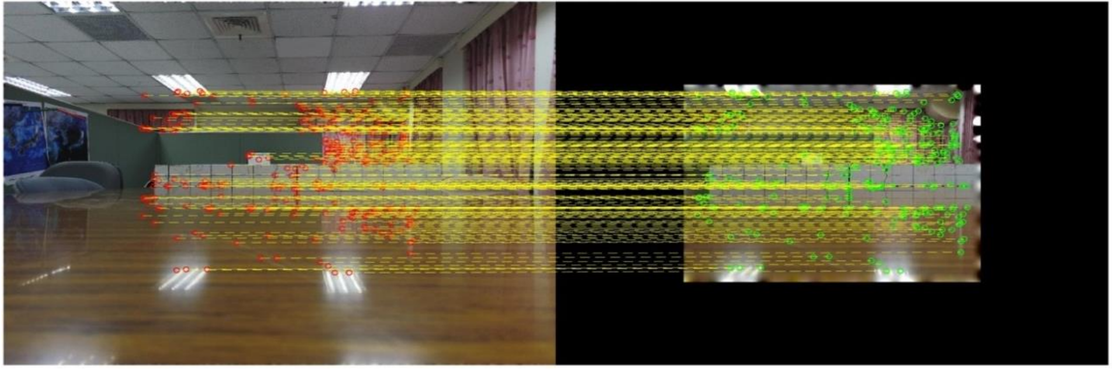


Figure 9. Image registration of 2x and 1x images.

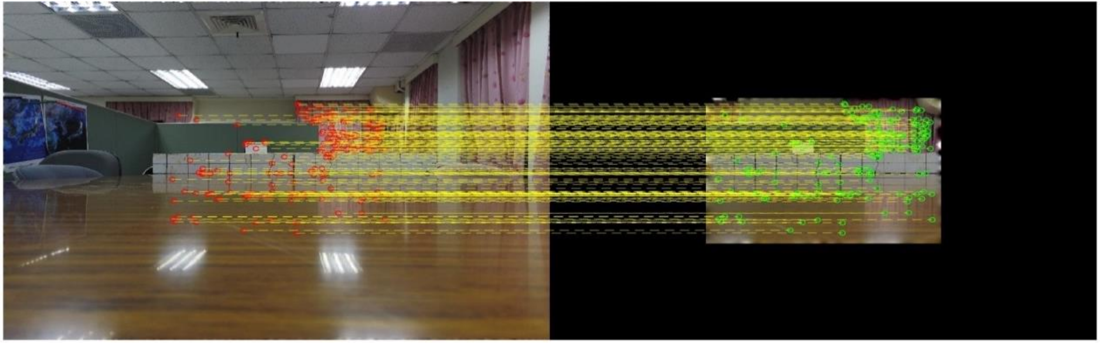


Figure 10. Image registration of 2.5x and 1x images.

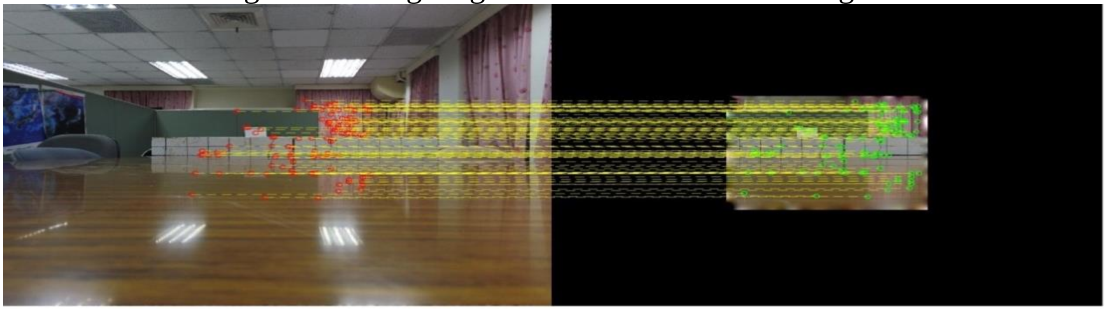


Figure 11. Image registration of 3x and 1x images.

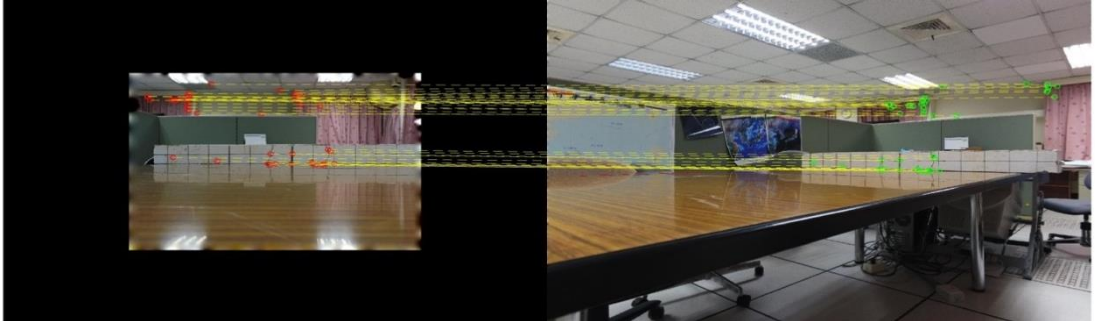


Figure 12. Image registration of the 2x image and the 1x image taken from the side.

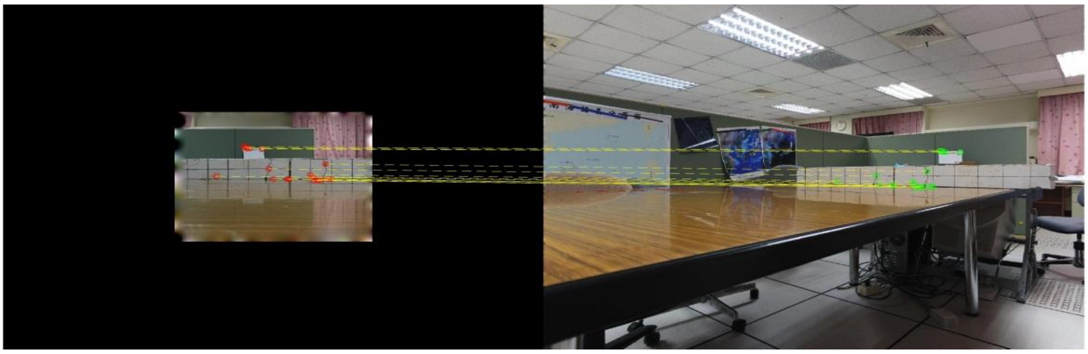


Figure 13. Image registration of the 3x image and the 1x image taken from the side.

3.3 Crack size measurement

The preliminary research measure crack sizes on 1x, 1.5x, 2x, 2.5x, 3x images manually with ERDAS IMAGINE 2013. Since cracks that are thinner than 0.3mm has little chance to cause damage on structures (Adhikari et al., 2013), this research only targets cracks wider than 0.3mm. As shown in Figure 14, cracks are marked with yellow (a), orange (b), light blue (c), and green (d). In this experiment, we measure crack lengths by sketching the segmentations of four cracks. Considering the crack will have different widths due to its propagation, we select one cross-section on each crack, as shown in Figure 15, for crack width measurement.

Overall, the proposed solution can measure crack lengths with 3.97mm root mean square error (RMSE), -0.93mm mean absolute error (MAE) and 3.58% mean relative error (MRE) and measure crack widths with 0.33mm RMSE, -0.0055mm MAE and 20.29% MRE.

According to the crack length measurement, crack (c) with relatively larger error has several erosions, which may lead to the misjudgment of the end points of cracks. A pixel size plays an important role in the crack width measurement. When the reference width is close to the pixel size, it is difficult to determine edges of cracks, which may cause larger errors. Thus, high-resolution images are always preferable.

In addition, as reference data were measured by two surveyors and the cracks are thin, it is difficult to identify the precise location of edges even for the surveyors. To be specific, there are 0.05mm to 0.2 mm differences between the measurement of two surveyors.

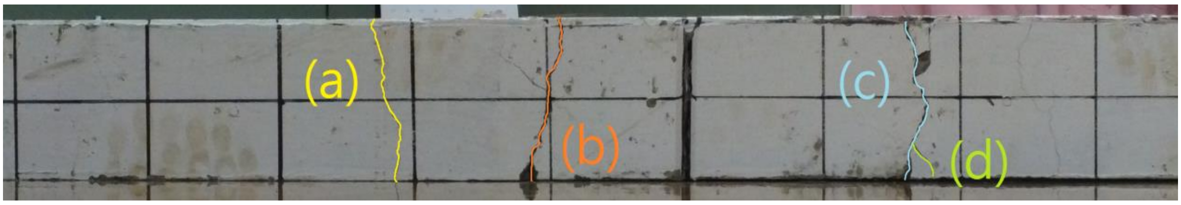


Figure 14. The distribution of four cracks.

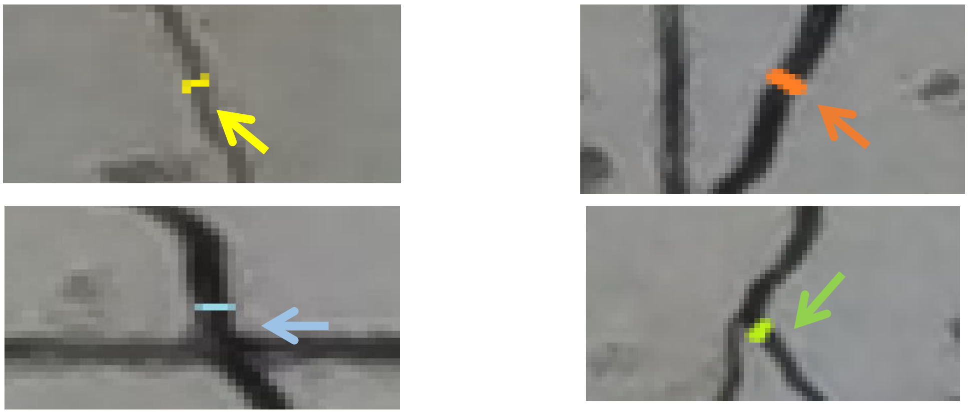


Figure 15. The selected sections of (a), (b), (c), (d) cracks.

4. Conclusions and future work

This research proposes a procedure of applying UAV and image registration on concrete bridge crack inspection. For the camera calibration, we develop a workflow for digital zoom cameras to calibrate images taken in different zooms. According to the result of image registration, SIFT is an image registration method that can find matched points on images taken in different scales and orientations. Lastly, this research measures four crack lengths and widths manually. As the results shows, the proposed solution can measure crack lengths with 3.97mm RMSE, -0.93mm MAE and 3.58% MRE. According to the measurement of crack widths, the proposed solution measure crack widths with 0.33mm RMSE, -0.0055mm MAE and 20.29% MRE. However, as the result shows, even by manual measurement, it is still challenging to identify the edges of cracks, so the results could easily be affected subjective judgements.

Overall, there are four main contributions in this preliminary research. (1) We propose a safe and efficient concrete crack inspection method by using UAVs. (2) We present a camera calibration workflow for digital zoom cameras to reduce errors caused by lens distortions. (3) For the long-range and close-up image registration, we demonstrate that the SIFT is an image matching method that can accommodate scale and orientation changes. (4) We identify potential issues for crack measurement that could help lead to future research improvements.

In our future work, the overall workflow and the methods of camera calibration and image registration proposed in this research will be continued. We also plan to apply machine learning or deep learning methods to extract concrete cracks automatically and provide a more objective answer to crack sizes by avoiding manual measurements. Experiments on real concrete bridges will be conducted to examine the applicability of the proposed solution in real-world scenarios.

5. Reference

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