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Detection and Length Estimation of Cracks in Enhanced Underwater Concrete Structure Images using Image Processing

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***Abstract*: Underwater concrete structures crack detection and computing the length of the crack formed on those structures is arduous. The development of underwater concrete structures is increasing rapidly. A well-organized, systematic inspection of the cracks is required to ensure the safety of the people, strength and life of the concrete structures. Cracks occurring on concrete structures are a result of heavy load on the structures, low-quality materials used during construction, temperature changes, haze and underwater environment conditions. Inspecting deep inside the water is a challenging issue. Hence, digital cameras often equipped in submarines are opted to visualize, observe and capture images of the concrete structures on inspection. The images acquired from the underwater environment consist of noise, suspended particles, uneven, non-uniform, low contrast, and low-light conditions. This paper aims to enhance the low-light underwater images using dual illumination estimation, reduce the noise from the images, remove the suspended particles, detect the crack formed on the concrete structure and calculate the length of the crack. The enhanced underwater images of the cracks present on concrete structures produced by the proposed algorithm can be easily identified by the observer. The length of the crack determines a specific treatment method to treat the crack. The proposed model targets to detect the crack and compute the total length of the crack formed on the underwater concrete structures.**

***Keywords*: Crack detection, Dual illumination estimation, Image noise reduction, Image processing, Length of the crack, Median filter, Underwater concrete structures, Underwater image enhancement.**

1. Introduction

Underwater structures are a gold mine for research in hydrologic sciences. Underwater concrete structures like bridges, dams, tunnels, underwater museums, monuments, etc are submerged. Further study and investigation are going on underwater structures to dig into history and analyse them. Nowadays, underwater concrete transport structures like bridges, railway tracks and tunnels around the globe are structured, systematic, cost-effective and well-organized.

Underwater concrete structures are prone to cracks, external effects and other marine effects. Cracks on concrete structures are a treacherous issue. Cracks occur due to various reasons like a heavy load, ageing of structures, usage of poor-quality materials during construction, etc. Concrete structures having perilous cracks need to be inspected and fixed from time to time. The dilapidation leads to the structures cave-in. Hence cracks should be detected and repaired regularly to ensure the safety, strength and life of the concrete structures. There are many methods present to treat and fill different types of cracks based on the length of the crack on concrete structures.

Digital cameras capture underwater images of concrete structures. Solar images are an advanced method to capture images of concrete structures containing cracks. The captured images have noise, haze and distortion. These underwater images are dark, low resolution and blurred. Deep water images are usually dark because sunlight does not reach the bottom of the water due to plankton or algae blocking the sunlight at the water's surface. The red wavelength of light scatters as soon as the light passes through the water. Only blue and green wavelengths of light remain in the depth of water. These are the reason for low-illuminated, dark and blurred underwater images. The aquatic life, their remains and dust account for the haze and noise in the captured image. In addition to this, noise gets added at the time of capturing and processing the underwater image.

Median filter is used to remove the noise. It is a nonlinear filter where its mathematical analysis is relatively complex for the image with random noise. For an image the noise variance of the median filtering under normal distribution with zero mean noise is

$$\sigma_{med}^2 = \frac{1}{4n\, f^2(\overline{n})} \approx \frac{\sigma_i^{\;2}}{n + \frac{\pi}{2} - 1} \cdot \frac{\overline{\pi}}{2}.$$

where σ_i^2 is the variance also known as input noise power, n is the size of the median filtering mask, f (n) is the function of the noise density and the noise variance of the average filtering is

$$\sigma_0^2 = \frac{1}{n}\sigma_i^2.$$

The effects of median filtering depends on the size of the

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median filtering mask and the distribution of the noise in the image. The image noise reduction effect can be evaluated by the signal to noise ratio (SNR). Let us assume an original image to be f (i, j) and its size as M x N. The processed image is f_{OUT} (i, j) where i = 1,2,..., M and j = 1,2,..., N. Then we have,

$$SUM = \frac{\sum_{i}^{M}\sum_{j}^{N} f(i,j)^2}{\sum_{i}^{M}\sum_{j}^{N} (f_{OUT}(i,j) - f(i,j))^2}$$

$$SNR = 10\lg(SUM)(dB).$$

The proposed model uses a dual illumination method to enhance and illuminate the captured dark underwater image, remove noise from it, detect a crack present on the concrete structure from the enhanced noise-free restored captured image and calculate the overall length of the crack. The proposed method works on the underwater image from any optical camera regardless of its specifications.

2. Materials and Methods

In this paper, the proposed model aims to enhance the image of concrete structures located under the water, detect the crack present in them and find their length. The algorithms of the proposed model are computed in MATLAB 2020 and Jupyter notebook. The underwater concrete structure crack images used as the input images are respectively of size 7.56 KB and 10 KB. The dimensions of the image are 312 x 378 pixels and 330 x 297 pixels. The experiments are conducted in a PC with a 2.6 GHz CPU and 8 GB of RAM.

Fig. 1. Images of cracks on underwater concrete structures

3. Existing Model

The existing models detect the cracks present in the dams and bridges. Further, the models classify and predict the type of cracks formed on those structures through deep learning and machine learning algorithms. However, when the model is applied to the crack image embedded with noise having a pixel value different from the background is often judged as a crack, resulting in a decrease in the accuracy of the crack. The dual illumination estimation method enhances the images of low-light atmospheric conditions. In dual illumination estimation, the first pass estimates forward illumination to correct underexposed regions, while the second pass computes the inverted input image to obtain reverse illumination to correct the over-exposed regions. This is a two-pass illumination estimation algorithm to correct the regions of multi-exposure atmospheric conditions. This algorithm is not yet analyzed for deep aquatic conditions.

4. Proposed Model

The proposed method aims to detect and determine the length of the cracks formed on underwater concrete structures like tunnels, dams, bridges, swimming pools, museums, monuments, etc. The underwater images are acquired using digital cameras. There are no specific requirements on the type of optical cameras used to capture the images. The model has no restrictions on the dimensions of the image.

The deep water-acquired images have dark, low-light and uneven illumination. The model employs dual illumination estimation on the captured concrete structure images in the deep dark aquatic environment. Forward illumination processes the input image captured from an optical camera in a low-light, dark marine environment. Reverse illumination processes the inverted input image. Both the illuminated images are blended to produce enhanced images of underwater concrete structures. The acquired underwater images from the digital cameras are now processed and enhanced.

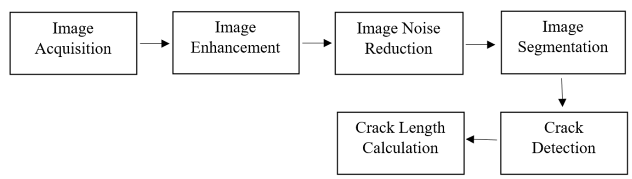

Fig. 2. Workflow of the proposed model

The model computes the enhanced image to remove noise from it. The enhanced image is passed to the median filter to remove noise. The noise has different pixel values. These pixel values are mistaken as background. Thus the pattern of the crack differs and an accurate crack is not detected. Thus, it is necessary to remove noise from the image for accurate predictions. The enhanced image is divided into red, green and blue channels. The median filter is applied to the red, blue and green channels. The median filter function is to enumerate the median value of the pixels in the image window of an odd-sized neighbourhood. The median filter in this algorithm works on the order of the image 5x5. The filtered image from the three channels is fused into a single noise-free restored image.

The restored noise-free image will now be computed for segmentation. The threshold value of the image will be calculated using Otsu's method. The image will be converted to a binary image based on the threshold value. The colour input image will now be converted to black and white pixels. The binary image is dilated and eroded. The segmented image contains disconnected pixels, gaps between pixels and isolated pixels. The gaps and small spaces between pixels are filled in such a way as to complete a pattern. The disconnected pixels are connected and the isolated pixels are removed. The pattern will be formed in the image. This pattern might be a line or any other shape. This pattern represents the crack in the underwater concrete structure image. The crack formed in the underwater concrete structure will be detected and visualized.

The length of the detected crack will be calculated. The algorithm used to calculate the length of the crack is Euclidean distance. The distance between the two farthest points will be evaluated and the length is determined. The distance measured will be converted to metres based on the area of the image. The length of the crack will be displayed concerning metres. The proposed model enhances the image, detects the cracks and computes the length of the crack formed in the underwater concrete structure images.

5. Results

The proposed algorithm in this paper detects the crack and determines the length of the crack formed on the underwater concrete structure. Initially, the model computes the input images for dual illumination estimation to enhance the low-contrast acquired image. The enhanced output images after dual illumination estimation are as follows.

Fig. 3. First input image

Fig. 4. Second input image

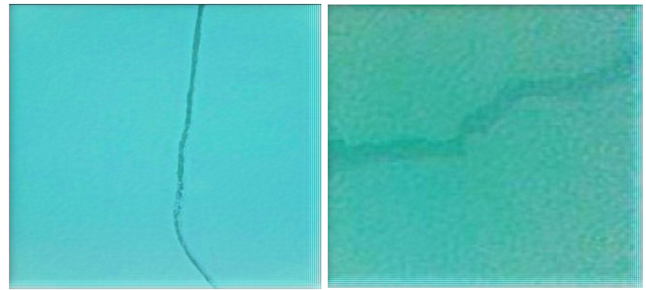

Fig. 5. Forward illumination enhanced images of cracks

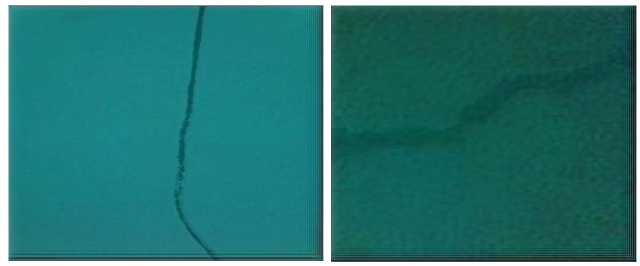

Fig. 6. Reverse illumination enhanced images of cracks

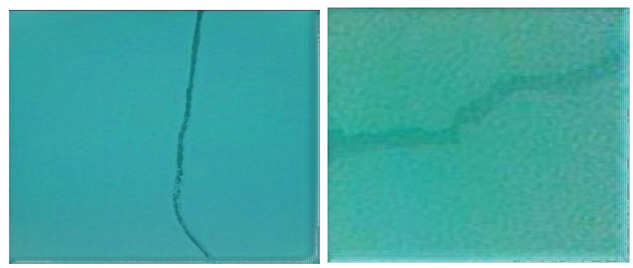

Fig. 7. Dual illumination estimation enhanced image of cracks

The histogram of the input images and enhanced images are computed to analyze the intensities of the images. The histograms of the input images and the comparison of the histograms between the input images and the enhanced images are shown below. The x axis of the graph represents the image pixel values range. The y axis represents the frequency. The red, green and blue components in the graph are the intensity levels of RGB pixels in the input images.

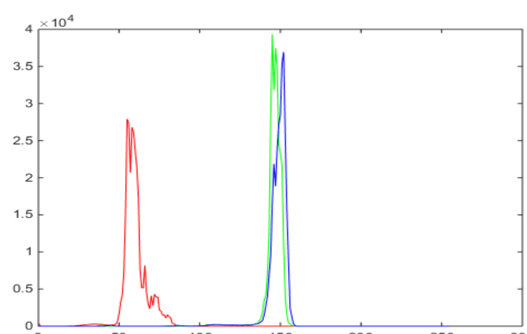

Fig. 8. Histogram of first input image

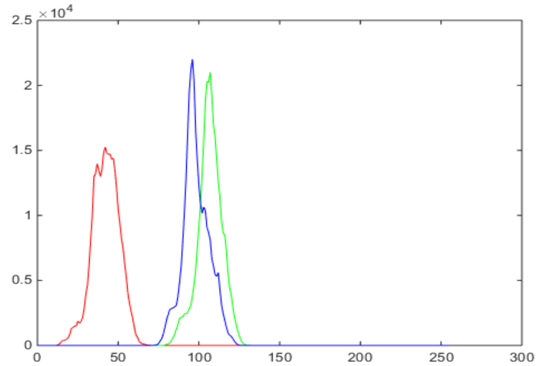

Fig. 9. Histogram of second input image

The histograms of the input images are compared before and after the image enhancement. In the graphs plotted below for gray level scale (0-255) vs frequency, the pixel values range in 50 -150 before enhancement. After image enhancement the pixel values range from 150 -255. The dual illumination estimation which we used to enhance underwater image have enhanced the image thereby increasing the intensity levels of the pixels in the input images.

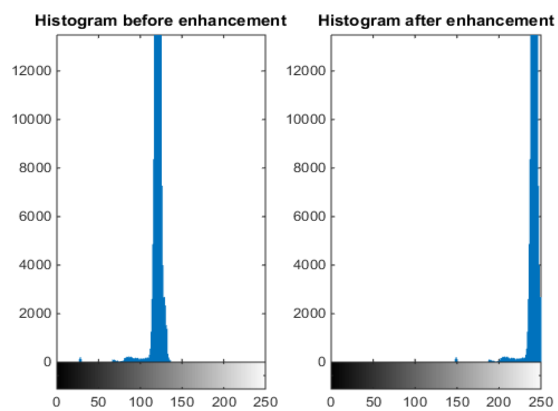

Fig. 10. Comparison of histogram before and after image enhancement of first input image

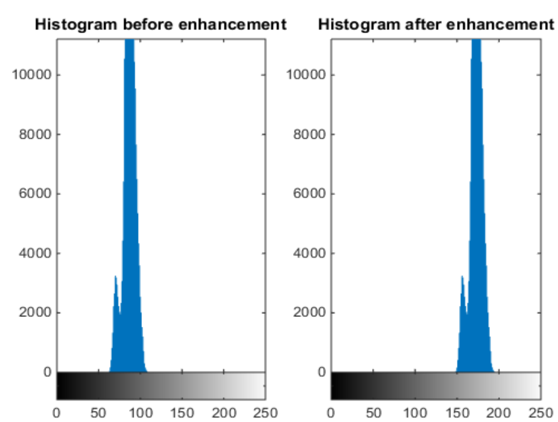

Fig. 11. Comparison of histogram before and after image enhancement of second input image

The dual illumination estimation enhanced output images from the underwater environment is obtained from the model. The enhanced images contain noise in it. These output images are passed as input to the median filter to remove noise and produce a restored image. After filtering, the signal to noise ratio of the first input image is $SNR_1 = 0.9709$ and the second input image is $SNR_2 = 0.96481$. The obtained signal to noise ratio shows that the noise is being removed from image. The noise reduction images are obtained as follows.

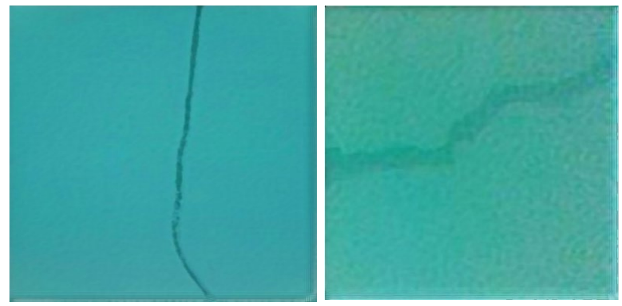

Fig. 12. Restored noise reduction images

The restored output images are filtered to remove noise from the enhanced image. The filtered images are given as input for image segmentation. The images are segmented and converted to binary images.

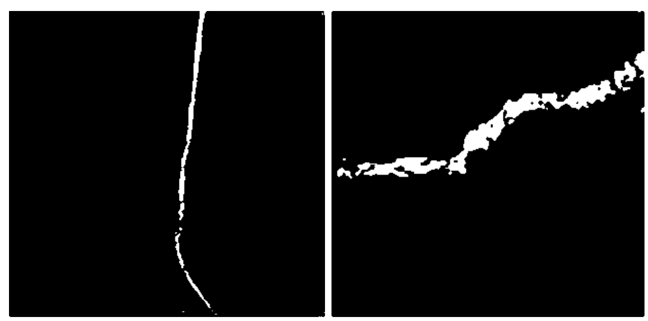

Fig. 13. Segmented binary images

Further, the binary images are dilated and eroded to detect cracks. The crack is detected from the input segmented images. The threshold value for the first input image is $T_1 = 0.4200$. The threshold value for the second input image is $T_2 = 0.2800$.

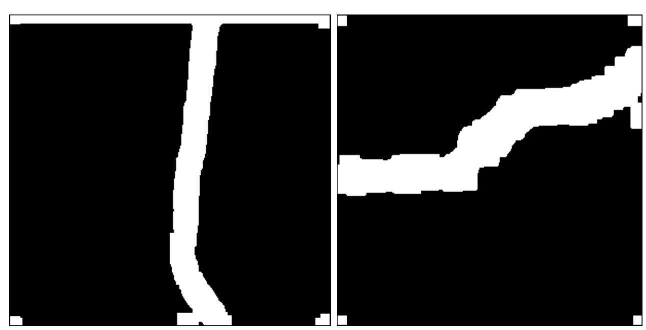

Fig. 14. Dilated images

The segmented image contains disconnected pixels, gaps between pixels and isolated pixels. The gaps and small spaces between pixels are filled based on the threshold value of the binary image. The disconnected pixels in the binary image are connected and the isolated pixels from the images are removed.

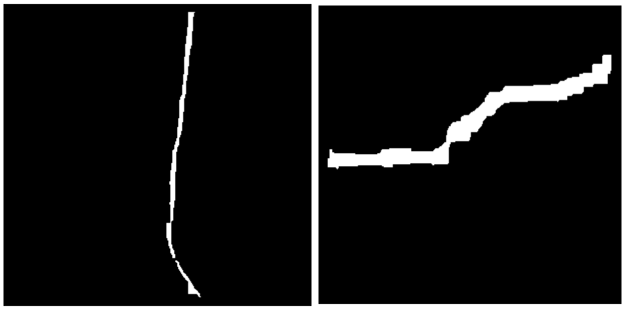

Fig. 15. Eroded images

The white pixels in the segmented binary image depict the cracks. The pattern can be observed from the images. Thus, the pattern formed is the crack. Henceforth, the crack formed on the concrete structures is detected. The detected crack output for the input images is displayed below.

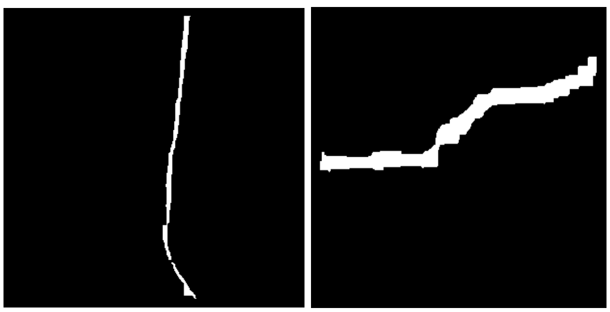

Fig. 16. Images of crack detection

The length of the detected crack is calculated and converted into metres based on the area of the image. The area parameter is given as an input to compute the length of the crack. The algorithm used to determine the length of the crack is Euclidean distance. The area for both of the above input images is given as 5 square metres. The length is calculated as per the mentioned area of the images. The calculated length of crack detected images is displayed below.

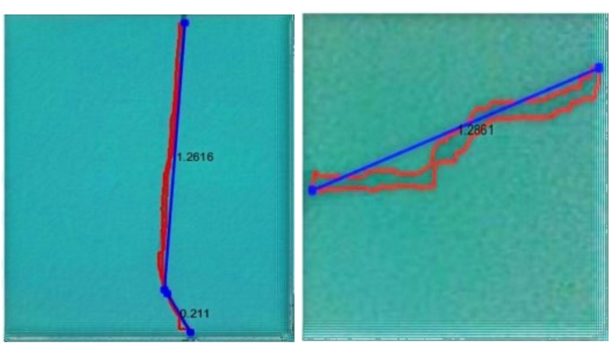

Fig. 17. Length of the cracks on the underwater concrete structure input images

6. Conclusion

The proposed model is an approach to detect the cracks and calculate the length of the cracks formed on underwater concrete structures like bridges, dams, tunnels, swimming pools, underwater museums, monuments, hidden cities, etc. The proposed method enhances the underwater images acquired from uneven illumination, low-contrast, dark, low-light and noisy deep aquatic environments. The algorithm removes the noise from the image and has high computational power as well as effective signal to noise ratio. There are no specific requirements on the type of digital cameras used to acquire images. The proposed algorithm gives accurate results for the input images irrespective of the size, dimensions, illumination and noise. The proposed work determines the accurate length of the crack based on the actual area of the underwater concrete structure in the input image. There are different crack treatment methods to treat a specific type of crack based on the length of the crack formed on the concrete structures. The proposed work helps engineers to analyze and determine specific treatment methods to heal the crack in a short period. The proposed algorithm works efficiently in the complex, non-uniform, low-light illuminated underwater environment to detect the crack and computes the length of the crack formed on the underwater concrete structures.

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