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Gabor filter based image segmentation for detecting damages on surface of reinforce concrete structures

Phát hiện các khuyết tật trên bề mặt kết cấu bê tông cốt thép sử dụng kỹ thuật phân ngưỡng ảnh dựa trên bộ lọc Gabor

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Abstract

Periodic structural health survey is an important task to ensure the safety and serviceability of buildings. This study aims at developing a computer vision tool to segment images capturing surface of reinforced concrete structures. The image processing technique of Gabor filter is used with k-Means clustering algorithm and principal component analysis to automatically segment damages on concrete surface including spall, crack, bughole, and stain.

Keywords: Gabor Filter; Structural Health Survey; Concrete Damage; Computer Vision.

Tóm tắt

Khảo sát trạng thái kết cấu định kỳ là một nhiệm vụ quan trọng để đảm bảo sự an toàn và khả năng làm việc của công trình. Nghiên cứu của chúng tôi phát triển một công cụ dựa trên thị giác máy tính để phân tích hình ảnh chụp từ bề mặt của kết cấu bê tông cốt thép. Các kỹ thuật xử lý ảnh gồm bộ lọc Gabor, thuật toán phân nhóm k-Means, và phân tích PCA được sử dụng để tự động hóa việc phát hiện các hư hỏng trên bề mặt bê tông bao gồm vết lở, vết nứt, lỗ rỗng, và vết bẩn.

Từ khóa: Bộ lọc Gabor; Khảo sát trạng thái kết cấu; Hư hỏng kết cấu; Thị giác máy tính.

1. Introduction

Due to the effects of excessive usage, structural aging, and inclement weather conditions, building components deteriorate over time [1]. Therefore, periodic structural health survey is a mandatory task to ensure the safety and serviceability of buildings. This task aims at detecting and reporting various forms of damages as early as possible to prevent harmful effects on occupants' heath [2]. The damages may be found in various forms including spall [3-7], crack [8, 9] [10-12], stain caused by algal

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colonization [13, 14], and bughole [15, 16]. Particularly, falling debris caused by concrete spalling can be particularly dangerous for occupants. Thus, it is highly desirable for maintenance agents to be equipped with intelligent tools to detect concrete spalling in a timely manner.

In recent years, the ease of access to low-cost digital cameras and a rapid advancement in the field of computer vision have paved the way for automated structural heath survey [17-25]. This process is conventionally notorious for its intensive time and labor consumption. With computer vision based models and high-quality cameras, the physical condition of civil structures can be continuously monitored and reported to maintenance agencies. This fact immensely enhances the productivity and objectiveness of the surveying process. Based on such motivation, this work develops a computer vision tool to segment images capturing surface of reinforced concrete structures. The image processing technique of Gabor filter is used with k-Means clustering algorithm and principal component analysis to automatically segment damages on concrete surface including spall, crack, bughole, and stain. Objects extracted from this process can be subsequently used for further measurements of shape properties and other sophisticated analyses.

2. Gabor Filter (GF) for Image Segmentation

The GF is an effective approach to identify and extract an object of interest from an image background [26-28]. This image processing technique is inspired from the multi-channel operation of the human visual system employed for visual interpretation [29-32]. A GF operation includes two-dimensional Gabor filters described as complex sinusoidal waves modulated by Gaussian envelopes [29]:

$$h(x, \mathrm{y}) = \exp\{-\frac{1}{2}[\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}]\}\cos(2\pi\,\mathrm{u}_0\mathrm{x}) \quad (1)$$

where u_0 represents the frequency of a sinusoidal plane wave along the x-axis. σ_x and σ_y denote the space constants of the Gaussian envelope along the x and y axes, respectively.

The frequency domain representation of the GF is given by [33]:

$$H(u,v) = A(\exp\{-\frac{1}{2}[\frac{(u-u_0)^2}{\sigma_u^2}] + \frac{v^2}{\sigma_v^2}\} + \exp\{-\frac{1}{2}[\frac{(u+u_0)^2}{\sigma_u^2}] + \frac{v^2}{\sigma_v^2}\}) \quad (2)$$

where $\sigma_u = \frac{1}{2}\pi\sigma_x$, $\sigma_v = \frac{1}{2}\pi\sigma_y$,

and $A = 2\pi\sigma_x\sigma_y$.

3. Image segmentation using Gabor filter and k-Means clustering

The process of image segmentation used for detecting damages on concrete surface can be broken down into several steps:

(i) Image gray scale conversion: In this step, an original image is converted into a gray-scale image.

(ii) Image smoothing: The commonly used median filter with a window size of 4 pixels is applied to smooth the gray-scale image and remove noise.

(iii) The GF operation: This study employs the GF to automatically identify area of interest that contains the damages.

(iv) Principal Component Analysis (PCA): After the GFs are computed, the PCA is utilized to transform the set of GFs and reduced the data dimensionality. The number of the PCA transformed data is determined so that a 99% of cumulative variance explained is achieved.

(v) Data clustering: Based on the result obtained from the PCA, this study employs the unsupervised data analysis approach of K-means clustering [34]. This unsupervised learning tool is used to automatically divide an image into distinctive regions. Based similarity index such as Euclidean distance, image pixels that have the similar properties can be grouped in one cluster.

It is noted that the GF, PCA and K-means clustering operations are attained via built-in functions provided by the Accord.NET Framework [35]. The overall integrated model has been developed by the Visual C# .NET framework 4.6.2. The K-means clustering algorithm with the number of cluster = 2 is used to segment the image sample into damage objects and background.

4. Experimental results

In this section, the performance of the newly developed program used for concrete damage detection is demonstrated four categories of defects. The collected images have been collected by the Cannon EOS M10 (CMOS 18.0 MP). The size of an image sample is fixed to be 128x128 pixels. The analysis results are reported in **Fig. 1** (spall object detection), **Fig. 2** (crack object detection), **Fig. 3** (stain object detection), and **Fig. 4** (bughole object detection). As can be observed from these figures, the integrated computer vision model has successfully extracted the damage objects of interest.

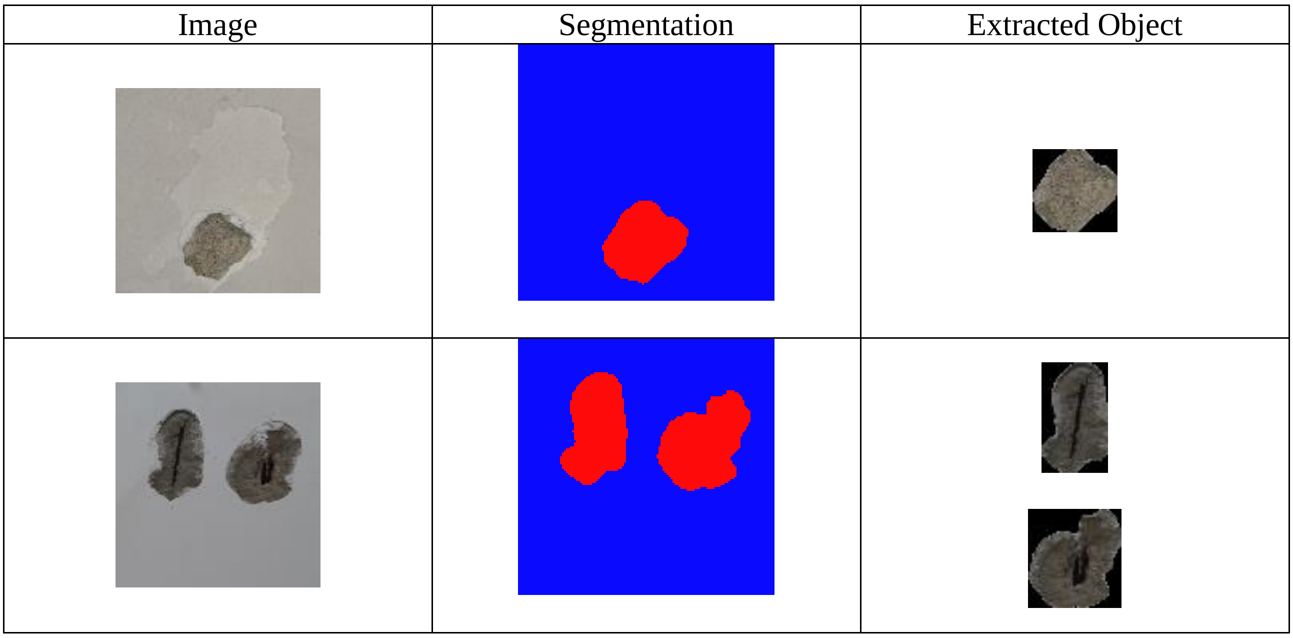
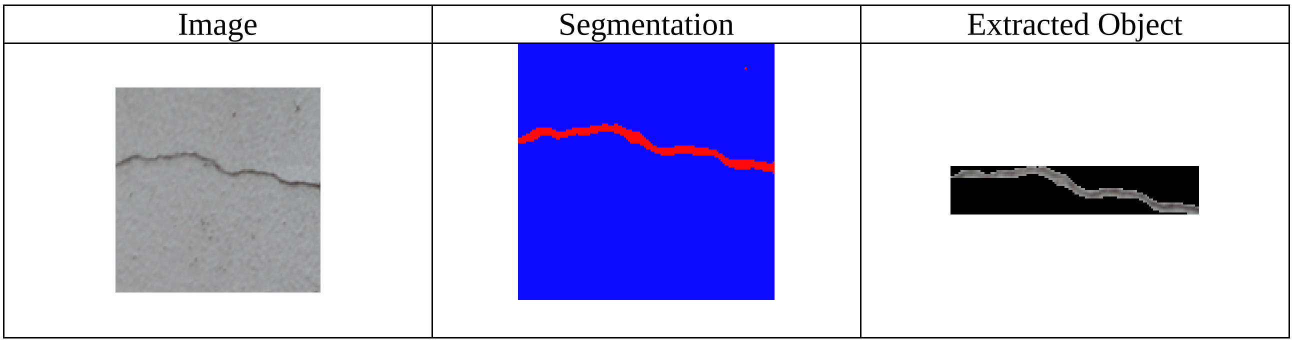


Fig. 1 Image segmentation results and extracted spall objects



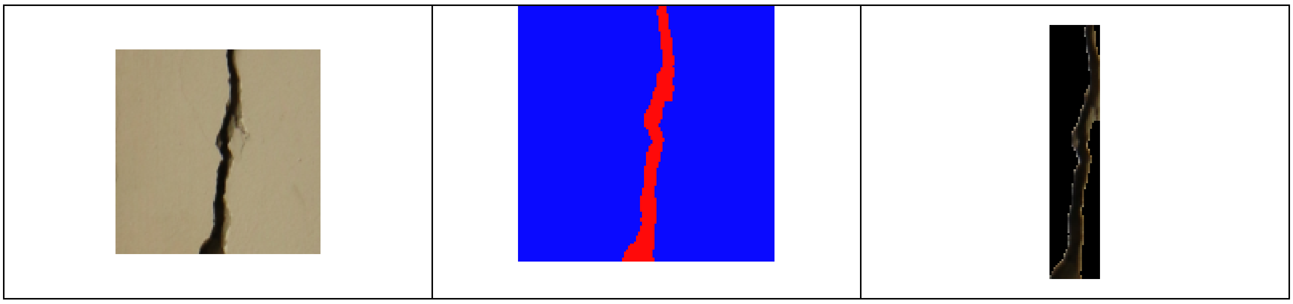


Fig. 2 Image segmentation results and extracted crack objects

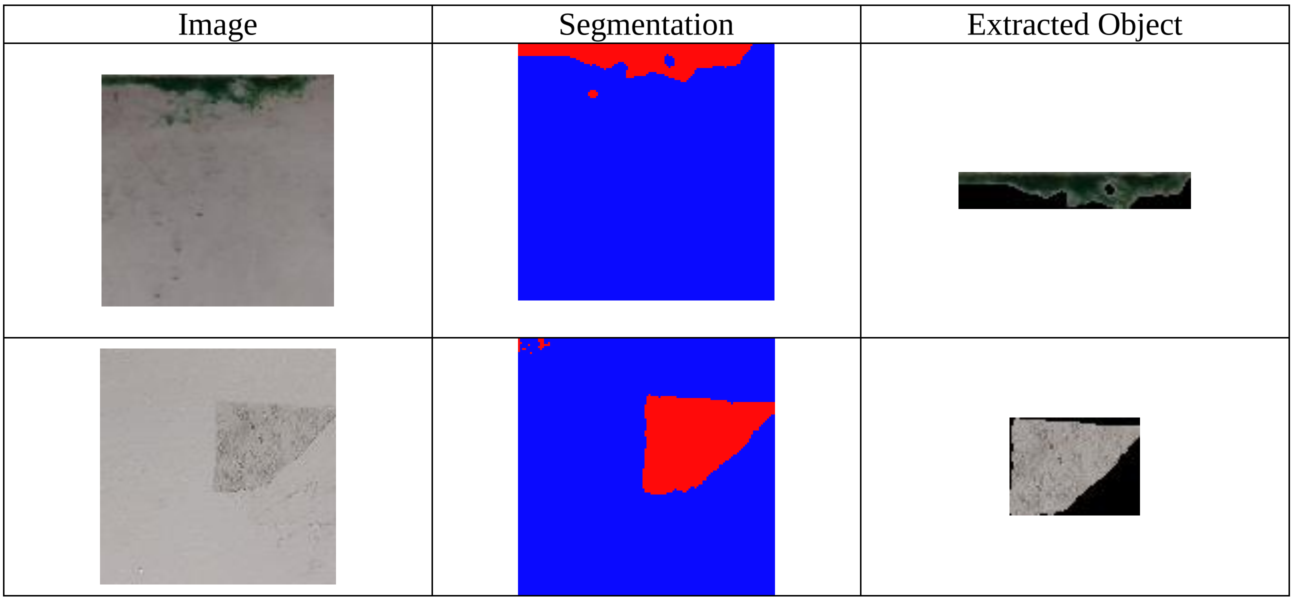


Fig. 3 Image segmentation results and extracted stain objects

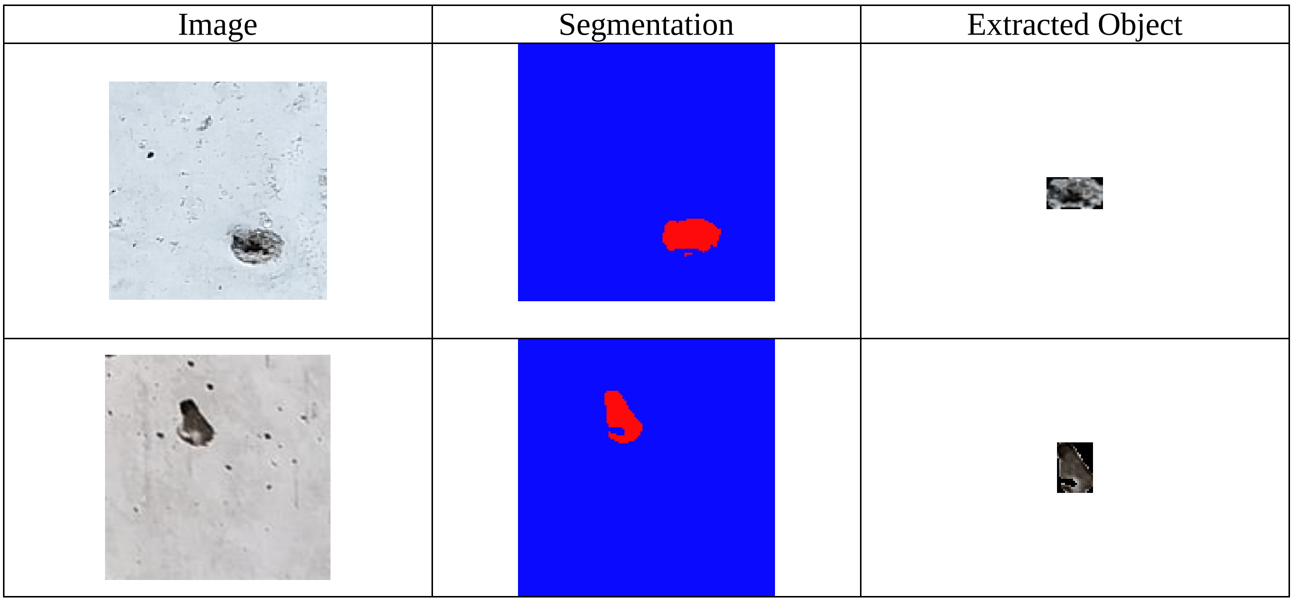


Fig. 4 Image segmentation results and extracted bughole objects

5. Concluding remarks

Periodic survey of structural heath condition is a vital task in building maintenance operation. To enhance the productivity, objectiveness, and accuracy of this process, the current study has developed a computer vision model based on the applications of the GF, PCA, and k-Means clustering algorithms. To facilitate the application of the model, a computer program developed with the Visual C# .NET framework has been constructed. The newly developed tool has been tested with four cases including the detections of spall, crack, stain, and bughole objects. Experimental results have demonstrated that the computer vision model developed in this study can be a helpful tool to assist building maintenance agencies in the task of periodic surveys. Future extensions of the current study may include the investigation of other advanced image processing algorithms for image segmentation.

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