Measurement of Crack Damage Dimensions on Asphalt Road Using Gabor Filter

D R Sulistyaningrum1*, B Setiyono1, J N Anita1 and M R Muheimin1
1Department of Mathematics, Institut Teknologi Sepuluh November
Campus ITS, Sukolilo, Surabaya, 60111, Indonesia

*e-mail: dwiratna@matematika.its.ac.id

Abstract. Cracks are a type of road defect that is often found on highways. Crack dimension information is needed in the process of road maintenance and repair. Image processing methods have been widely used for visual detection of damage. One of them is the Gabor filter method, which has been used for texture-based defect detection. In this study, the detection and measurement of crack dimensions on the asphalt road have been carried out using Gabor Filter. The steps to measure crack dimensions consist of image acquisition, pre-processing, segmentation, labeling, and dimension measurement. The results of experiments on 15 crack images showed that the method's accuracy reached 95.191% for the crack area length and 87.935% for the crack area width.

Keywords: road defect, crack dimension, Gabon Filter, image Processing, crack detection

1. Introduction
The road is one of the infrastructures that can connect one region to another. Streets also have a vital role in supporting the economic, social, and cultural fields and various other aspects of people's lives. Road conditions influence various community activities. The high level of community activity will be directly proportional to the high traffic burden. High traffic loads will increase road loads and cause road pavement damage. Damage to the road can cause discomfort and threaten the safety of road users.

The cause of road damage can start from small cracks that appear on the surface of the road. Over time these cracks can become large holes caused by certain factors, such as weather and the number of vehicles that load heavy loads through the road [1]. Thus, it is necessary to check the highway condition as an effort to maintain the safety and comfort of road users. Detection of road damage is one of the important steps in checking road conditions. Checks are carried out to plan an effective road maintenance process and for better road conditions. Some of them are types of damage such as holes or cracks, the degree of damage, location, width, length, area, and possibly depth of road damage [2].

Cracks are one of the most common types of damage encountered on road surfaces. There are various types of road cracks ranging from single cracks (longitudinal and transverse cracks) to interconnected cracks and spreads on the road surface (beam cracks, crescent-shaped cracks, and crocodiles) [3]. In the process of checking road conditions, it is necessary to measure the road cracks' dimensions.

Examination of road conditions was previously carried out conventionally using human labor by checking directly on road conditions. However, as technology develops, human labor has been replaced by automatic data collection using some image data that can be processed with specific algorithms. In
several previous studies, road damage detection has been carried out by various methods and using multiple types of images.

Crack detection studies on the surface of the highway that have been done are crack detection use a combination of thresholding, Median filter, and morphological closing. The combination of methods used can detect the presence of cracks with an accuracy of 85% and a processing speed of 4.25 seconds per image [4]. Also, research about crack detection was done using 2D wavelet transforms[5,6]. The 2D wavelet transforms increases or clarifies cracks but also increases noise.

Another study was carried out by Yong Shi and friends [7] by performing automatic crack detection using the random structured forest method. The method produces a high-performance crack detector, which can identify complicated crack types. Besides, the research also proposed a new crack descriptor to characterize the crack and distinguish it from noise effectively.

One method that can be used for the segmentation of cracks in two-dimensional images is the Gabor filter. Gabor Filters have been used for the detection and classification of defects on metal surfaces [8], detection of defects in steel plates [9], as well as for detection of defects in bullet casings [10].

This paper measures the dimensions of the longitudinal, transverse, and diagonal cracks on the paved road surface. The crack detection process is carried out through the segmentation process using a digital image-based Gabor filter.

2. Method

The process of measuring the dimensions of the road cracks in this study consists of six main operations, as shown in Figure 1. The five stages are pre-processing, image segmentation, labeling, and dimension measurement. An explanation of each method will be given in the following description.

\[ G(\lambda, \theta, \varphi, \sigma, \gamma, x, y) = \exp \left( -\frac{x'^2 + y'^2}{2\sigma^2} \right) \cos \left( 2\pi \frac{x'}{\lambda} + \varphi \right) \]

with

\[ x' = x \cos \theta + y \sin \theta \]
\( y' = -x \sin \theta + y \cos \theta \)

The parameters used in the Gabor function are as follows:

a. \( \lambda \), is the wavelength of the cosine factor in the Gabor filter.

b. \( \theta \), is the orientation of the normal line to the line parallel to the Gabor function.

c. \( \varphi \), is an offset phase. Valid values are between \(-\pi\) to \(\pi\) [11].

d. \( \gamma \) is a spatial aspect ratio that determines the Gabor function's ellipse with a default value of 0.5 [11]

e. \( \sigma \), is the standard deviation of the Gaussian factor of the Gabor function. Value can be changed via bandwidth value (b). The spatial frequency flow (bandwidth) of the Gabor filter is related to the ratio \( \frac{\sigma}{\lambda} \) shown in the following equation:

\[
b = \frac{\sigma}{\lambda} + \frac{\sqrt{\ln 2}}{2}
\]

(2)

\[
\frac{\sigma}{\lambda} = \frac{1}{\pi} \sqrt{\frac{\ln 2}{2}} \cdot \frac{2^b + 1}{2^b - 1}
\]

(3)

from equations (2) and (3) the following equation is obtained:

\[
\sigma = \frac{\lambda}{\pi} \sqrt{\frac{\ln 2}{2}} \cdot \frac{2^b + 1}{2^b - 1}
\]

(4)

The size of the Gabor filter kernel can be obtained by calculating the values of \( x \) and \( y \) using the following equation:

\[
\sigma_x = \frac{\sigma}{\gamma}
\]

(5)

\[
\sigma_y = \sigma
\]

(6)

From the \( x \) and \( y \) values that have been obtained, use the following equation:

\[
z = 8 \times (\sigma_x, \sigma_y)
\]

(7)

The value of \( z \) that has been obtained is rounded down to calculate the value of \( U \) with equation (8).

\[
U(z) = \begin{cases} 
z + 1, & z \mod 2 = 0 \\
0, & \text{other}
\end{cases}
\]

(8)

so we get the Gabor kernel filter size is \( U \times U \).

2.2. Image Morphology

Mathematical morphology is a spatial structure analysis technique that aims to analyze the shape and format of objects in binary and grayscale images. Operations on mathematical morphology are carried out to identify objects, eliminate noise in images, and other needs. In the methodology of binary image morphology, there are four primary operations [12], namely dilation, erosion, opening, and closing. Dilation is a morphological transformation that combines two sets using the addition of vectors of set elements. Erosion is a dual morphology of dilation. Erosion is a morphological transformation that combines two sets using the operation of removing set elements. The opening is an erosion operation that is followed by dilation using the same structural elements. Closing is a dilation operation followed by erosion using the same structural elements.
Some methods are a combination of several basic morphological operations, including bridge operations. Bridge operation connects pixels separated by a single-pixel gap. This operation is done by setting pixels 0 to 1 if they have two unconnected neighbors.

![Figure 2. Illustration of Bridge Operation Process](image)

2.3. Connected Component Labelling
Connected Component Labelling is one algorithm that can be used to classify regions or objects in digital images. This algorithm utilizes the theory of pixel connectivity in images. Pixels in a region can be connected (there is connectivity) if they meet the adjacency rules. According to Gonzales and Woods [8], there are two types of connectivity used in two-dimensional imagery, namely:

a. 4-connected: horizontally and vertically N4 (P). This collection of pixels is called the 4-neighbors of P.

b. 8-connected: Adjacent pixels are said to have an 8-connected relationship if the pixels are located side by side horizontally and vertically N8 (P) or called four diagonal neighbors.

2.4. Measurement of Crack Objects based on the shape
Dimension measurement is a process carried out to estimate the size of a crack that has been detected. Measurement of the detected crack feature's dimensions is done by estimating the length and width of the crack. In dimension measurement, the crack object is represented as a region with the ellipse shape approach, as shown in Figure 3. For each ellipse, the parametric form of the ellipse equation is used as follows:

\[ x = a \cos t, \quad y = b \sin t, \quad 0 \leq t \leq 2\pi \]  \hspace{1cm} (9)

\[ \left( \frac{x}{a} \right)^2 + \left( \frac{y}{b} \right)^2 = \cos^2 t + \sin^2 t = 1 \]

\[ \frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \]

![Figure 3. Illustration of Ellipse](image)

3. Experiments Design

3.1. Method design
The purpose of this research is to detect and measure the dimensions of road cracks based on digital images. The expected output is the result of the estimated crack dimension of the road represented by the value of the crack's length and width.
Input data in the form of color crack images. The crack image first goes through several preprocessing stages, including scaling, grayscaling, and normalization. The scaling process equals the size of the image before the next method is carried out. The image is resized to 160x240. The segmentation process is carried out using Gabor filters with 4 different orientations, namely 0, 45, 90, and 135. Filtered images are converted to binary images, which will then be processed using morphology to get the crack segmentation results. In the morphological image, the process of selection and identification of crack objects is required. This process begins with the labeling process to identify several cracked objects in an image. Dimension measurements are made by setting the main axis length as the length of the cracked area and the minor axis length as the width of the cracked area.

The testing process for crack dimension measurement is done by comparing ground truth image measurements and measurements on segmented images. The level of accuracy of measurements on the crack object can be known through the average error value on the two measurement results. The error value is calculated using equation (10):

\[
\text{error} = \frac{|\text{actual size} - \text{conjecture size}|}{\text{actual size}} \tag{10}
\]

3.2. Experiment

The data used are secondary data obtained from the research dataset conducted by Yong Shi et al. [6]. The data are taken consists of road crack image data, both transverse cracks, longitudinal cracks, and diagonal cracks. The size of each image is 320x480.

![Example of Data Input](image)

**Figure 4.** Example of Data Input: (a) Longitudinal Crack. (b) Diagonal Crack, (c) Transversal Crack

4. Result and Discussion

This section will show some of the effects of experiments that have been carried out. The image segmentation process aims to detect crack areas. Figure 5 shows the results after the segmentation process with the Gabor filters.

![Segmentation process](image)

**Figure 5.** Segmentation process. (a) Gabor filter results (b) Image have been converted to binary images. (c) morphological results
In Figure 5, (c), there is still noise in the resulting binary image. Therefore, a morphological process is carried out to produce an image like in Figure 5 (d). In other types of cracks, binary images that have gone through a morphological process still have noise. In the binary image, there are several objects other than cracks, as shown in Figure 6 (a). The labeling process is carried out to mark each object in a binary image. Objects that have significant axis length values less than the threshold will be deleted or removed.

![Figure 6. The process of labeling and selecting object cracks. (a) Binary image of morphological results. (b) The image of the labeling process. (c) Selected crack objects.](image)

Based on the results of several trials, the parameter value $\lambda = 2$ and bandwidth $(b) = 3$ are the most optimal values for the segmentation of road crack images. Table 1 shows the results of segmentation with a value of $\lambda = 2$ and bandwidth $(b) = 3$.

| No. | Input Image | Groundtruth Image | Segmented Image |
|-----|-------------|-------------------|-----------------|
| 1   | ![Input Image 1](image) | ![Groundtruth Image 1](image) | ![Segmented Image 1](image) |
| 2   | ![Input Image 2](image) | ![Groundtruth Image 2](image) | ![Segmented Image 2](image) |
| 3   | ![Input Image 3](image) | ![Groundtruth Image 3](image) | ![Segmented Image 3](image) |
| 4   | ![Input Image 4](image) | ![Groundtruth Image 4](image) | ![Segmented Image 4](image) |
| 5   | ![Input Image 5](image) | ![Groundtruth Image 5](image) | ![Segmented Image 5](image) |
The measurements of the length of the crack area in the ground truth image and the image segmentation results expressed in pixels are shown in Table 2.

**Table 2. Result of Crack Area Length Measurement**

| No. | Files Name | Measurement Results | Error Percentage (%) |
|-----|------------|---------------------|----------------------|
|     |            | Groundtruth image (pixel) | Segmented image (pixel) |
| 1.  | I018       | 285,449            | 320,897              | 12.418 |
| 2.  | I030       | 269,542            | 317,477              | 17.782 |
| 3.  | I069       | 307,075            | 331,401              | 7.922  |
| 4.  | I094       | 278,249            | 295,925              | 6.352  |
| 5.  | I095       | 280,077            | 297,176              | 6.105  |
| 6.  | I096       | 268,259            | 276,209              | 2.963  |
| 7.  | I098       | 269,544            | 274,852              | 1.969  |
| 8.  | I018       | 285,449            | 320,897              | 12.418 |
| 9.  | I030       | 269,542            | 317,477              | 17.782 |
| 10. | I069       | 307,075            | 331,401              | 7.922  |
| 11. | I094       | 278,249            | 295,925              | 6.352  |
| 12. | I095       | 280,077            | 297,176              | 6.105  |
| 13. | I096       | 268,259            | 276,209              | 2.963  |
| 14. | I098       | 269,544            | 274,852              | 1.969  |
| 15. | I018       | 285,449            | 320,897              | 12.418 |

Based on the measurement data of the crack length in Table 2, obtained an average relative error value of 4.809% or accuracy of the length measurement is 95.191%. Table 3 shows the results of the crack width measurement in the ground truth image and the segmented image that are expressed in pixels.

**Table 3. Crack Area Width Measurement Results**

| No. | Files Name | Measurement Results | Error Percentage (%) |
|-----|------------|---------------------|----------------------|
|     |            | Groundtruth image (pixel) | Segmented image (pixel) |
| 1.  | I018       | 28,3816             | 29,7469              | 4.811  |
| 2.  | I030       | 20,4253             | 24,6642              | 20.753 |
| 3.  | I069       | 17,5796             | 16,9032              | 3.848  |
| 4.  | I094       | 11,9882             | 13,2472              | 10.502 |
| 5.  | I095       | 20,4694             | 21,7738              | 6.372  |
| 6.  | I096       | 15,9372             | 20,3558              | 27.725 |
| 7.  | I098       | 19,4451             | 20,3653              | 4.732  |
| 8.  | I018       | 28,3816             | 29,7469              | 4.811  |
| 9.  | I030       | 20,4253             | 24,6642              | 20.753 |
| 10. | I069       | 17,5796             | 16,9032              | 3.848  |
| 11. | I094       | 11,9882             | 13,2472              | 10.502 |
| 12. | I095       | 20,4694             | 21,7738              | 6.372  |
| 13. | I096       | 15,9372             | 20,3558              | 27.725 |
| 14. | I098       | 19,4451             | 20,3653              | 4.732  |
| 15. | I018       | 28,3816             | 29,7469              | 4.811  |
Based on the data of crack width measurement in Table 2, the average relative error is 12.065%. So that the accuracy of the width measurement is 87.935%.

5. Conclusions
This research has successfully implemented crack dimension measurement in road images using a Gabor filter. The test results on the Gabor filter's parameter values show that the parameter values that produce the best segmentation image are \( \lambda = 2 \) and bandwidth \((b) = 3\). The percentage of accuracy in the crack dimension measurement process is 95.191% in the crack length measurement, and 87.935% in the crack width measurement.

References

[1] Lukman Al Hakim, M. (2015). “Studi Evaluasi Pelaksanaan Kebijakan Pemeliharaan Jalan di Kota Surabaya”, Kebijakan dan Manajemen Publik, Volume 3, Nomor 1, Januari-April 2015

[2] Mohan, A., Poobal, S. (2017). “Crack Detection using Image Processing: A Critical Review and Analysis”. Alexandria Engineering Journal

[3] Salman, M., Mathavan, S., Kamal, K., Rahman, M. (2013). "Pavement crack detection using the Gabor filter". Proceedings of 16th International IEEE Annual Conference on Intelligent Transportation System, Hal.2039-2044.

[4] Riyadi, S., Azra, R. A., Syahputra, R., Hariadi, T. K. (2014). “Deteksi Retak Permukaan Jalan Raya Berbasis Pengolahan Citra dengan Menggunakan Kombinasi Teknik Thresholding, Median Filter, dan Morphological Closing”. Simposium Nasional Teknologi Terapan

[5] Subirats, P., et al. (2006). “Automation of Pavement Surface Crack Detection using the Continuous Wavelet Transform”. IEEE International Conference on. Oct. 2006: Atlanta, GA

[6] Ouma, Y. O., Hahn, M. (2016). “Wavelet-morphology Based Detection of incipient linear cracks in asphalt-pavements from RGB camera imagery and classification using circular Random Transform”. Advanced Engineering Informatics 30 (2016), Hal.481-499.

[7] Shi, Y., Cui, L., Qi, Zhiqian, Meng, F., dan Chen, Z. (2016). “Automatic Road Crack Detection using Random Structured Forest”. IEEE Transactions on Intelligent Transportation Systems Vol. 17, No. 12, Hal.3434-3445.

[8] Tikhe, C. dan Chitode, J.S. (2014). “Metal Surface Inspection for Defect Detection and Classifcation using Gabor Filter”. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 6.

[9] Doo-chul, C., Yong-Ju, J. Jong Pil, Y, Sung Wook, Y. dan Sang Woo, K. (2012). “An Algorithm for Detecting Seam Cracks in Steel Plates”. International Journal of Industrial and Manufacturing Engineering, Vol. 6, No. 12.

[10] Khaerul Fahmi, M. (2013). “Pendeteksi Cacat pada Selongsong Peluru Berbasis Citra menggunakan Gabor Filter”. Jurnal Sains dan Seni POMITS Vol.2, No.1

[11] Grigorescu, S.E., Petkov, N. dan Kruizenga, P. (2002). “Comparison of texture features based on Gabor filters”. IEEE Trans. on Image Processing, Vol. 11, No.10, Hal.1160-1167.

[12] Gonzales, R.C. dan Woods, Richard E.(2002). “Digital Image Processing”. New Jersey. Prentice Hall