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Measurement of Road Surface Irregular Crack Width Based on Ferret and Second Order Moment

Liu Sheng[1], Wang Weixing[2] and Wang Fengping[3]

[1]Faculty of Higher Vacational and Technical Education,Xi'an University of Technology, Xi'an 710082,China
[2,3]School of Information Engineering, Chang' an Univ., Xi'an 710064,China
[1]ls7691010@126.com,[2]znn525d@qq.com,[3]467202822@qq.com

Abstract

In order to evaluate the damage of the road accurately, a Ferret subsection measurement method based on Invariant moment was proposed. First, it set a Ferret minimum external rectangular on the basis of the barycenter and spindle. The rectangular width was the result of crack width. It set the edge conditions for reducing the errors of measurement caused by the slender burrs. It allowed rectangular edge and targets to intersect. In order to section reasonably, a method based on distance map was proposed. In the extreme value points, the subsections image was finished. It ensured that the distance between two adjacent lines was longer than the crack width. Experimental data indicated that the percent of valuable information was higher, the measurement was accurate. It can meet the requirement of practical engineering.

KeyWords: *road surface; second order moment; Ferret algorithm; crack width; distance map*

1. Introduction

During the service phase of the road surface, the influence including climate changes, environmental differences, overload and man-made factors may produce the cracks with different shapes and sizes [1]. The crack width and length reflect the road damage degree, and the road damage degree will affect the durability, aesthetics and the security [2].

The traditional methods of crack detection are based on artificial vision, which means the crack width, the crack evaluation level and the estimate crack trend are obtained by manual measurement [3]. Due to the significant crack width changes, it will lead a low efficiency calculation by manual measure [4]. Therefore, the method relied on image processing provides a simple and effective way for road crack detection.

In this paper, we proposed a crack detection method based on Ferret and second order moment. In addition, the experiments are given to demonstrate the proposed method is precise, simple and effective, which can meet the actual traffic demand and not affected by environmental factors.

2. Ferret

The Ferret was firstly used to measure the dimensions of irregular geometry such as length, width and so on.

2.1. The Traditional Ferret

The traditional Ferret [5] can be described as follows: firstly, select a point randomly from the irregular graphics and make the tangent of the point; secondly, select a line that parallels to the tangent, then move the line to both side of the tangent respectively until it

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intersects or tangents with a point of the graphics. When the vertical distance of the two lines reaches to maximum, this distance will be the object length. When the vertical distance of the two lines reaches to minimum, this distance will be the object width.

Therefore we can calculate the length and width of irregular graphics. So, the length and width of irregular graphics can be calculated.

As shown in Figure 1, we can see that this algorithm has many disadvantages. Due to the target object has many points, it is difficult to choose two points as the width if the point has the same distance of the two target lines. This will affect the accuracy of the measurement results. In the past research, many researchers have used the method which adopted the same measurements at multiple angular directions, and then they selected the average value, or the median value, or the maximum value as the final measurement result.

From the continuous function perspective, this method would get infinite numbers of Ferret rectangular and the results tend to be more accurate, but it is not realistic. Another problem is that: the more number of Ferret rectangular are obtained, the amount of computation become bigger, so this process is time consuming and imprecise.

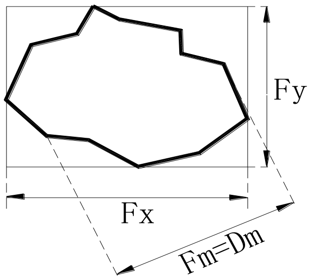


Figure 1. Irregular Graphics of Ferret Measurement

2.2. Ferret Based Second Order Moment

The gray-scale distribution function I(x,y)of irregular graphic image can be viewed as the probability density distribution function of 2D random variables. The different order moment have different meanings, such as the zero order moment represents total quality, the first order moment means the barycenter and the second order moment represents the size and direction of the image [6]. In theory, p + q order moment is invariant to the scale, translation and rotation. So we can simply determine the barycenter and spindle direction of an image [7].

The p+q order moment of discrete binary image I(x,y)can be defined as the follows [8]:

$$Mom(p,q)=\sum_x\sum_y x^p y^q I(x,y) \tag{1}$$

Where, p,q=0,1,2,3…

The center order moment formula is:

$$\mu(p,q)=\sum_x\sum_y (x-x_c{}^p)(y-y_c)^q I(x,y) \tag{2}$$

Where, x_c、y_c denotes the barycenter of image. The formulas are:

$$x_c=\frac{Mom(1,0)}{Mom(0,0)},\quad y_c=\frac{Mom(0,1)}{Mom(0,0)} \tag{3}$$

According to the center moment formula, we can get the angle between the spindle and

X axis. The formula is:

$$\tan 2\theta = \frac{2\mu(1,1)}{\mu(2,0) - \mu(0,2)} \tag{4}$$

Another way is expressed as:

$$1 - \tan^2\theta = \tan\theta \frac{\mu(2,0) - \mu(0,2)}{\mu(1,1)} \tag{5}$$

According to the formula above, the value of θ can be obtained, namely, the spindle direction and secondary axis direction can be determined. The spindle line and the secondary axis line both through the measured object barycenter, but they are vertical to each other which are shown in Figure 2.

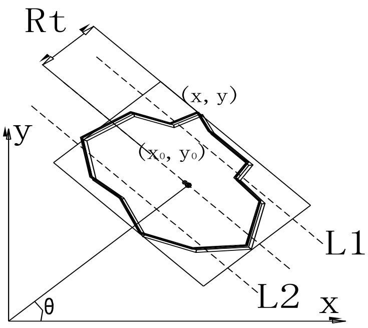


Figure 2. Spindle

After determining the spindle direction and secondary axis direction, the length and width of the irregular graphic are obtained by Ferret rectangular method. As show in Figure 3(a), firstly, determine a line L1 which overlap the spindle line; and then move L1 along the secondary axis direction to the one end, stop moving until L1 intersect with the irregular object contour. Meanwhile, determine another line L2, move it to the another end of the secondary axis direction in the same way. And L3 and L4 can also be determined. These four lines are the Ferret boundary, which is shown in Figure 3(b).

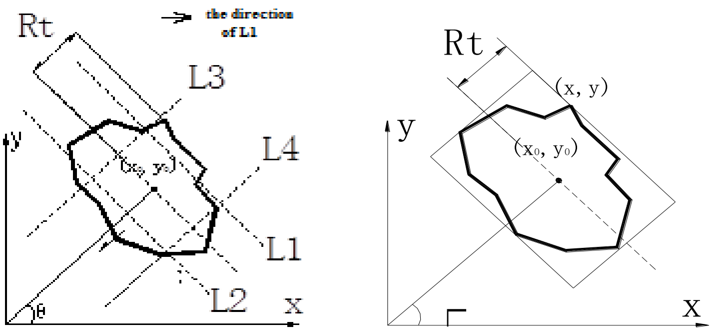


Figure 3. Ferret Based on Second Order Moment

2.3. The Boundary Conditions

In general, the contour line of irregular objects in binary image is smooth, so the above mentioned method can be used to get the Ferret rectangular. However, in special, the road crack exists burr which can't eliminate in de-noising process, correspondingly, the contour line in a binary image has a small number extension line generated by burr. If the number of the extension line is n(n≥1),the obtained external rectangular by the above method has n+4 intersections with the labeled object. When the extension line's length in a pixel point up to 5 or more than 5 pixels, or else the extension line's length in 2 or more than 2 pixels' width up to 5 or more than 5 pixels, the Ferret rectangular includes them whether or not depends on the number of intersections between the external rectangular length and the measured object. We can get the initial rectangular when the line stop moving, set the intersections' boundary conditions between the burr extension line with the initial rectangular. The formula is:

$$\tau = \frac{m}{M} \tag{6}$$

Where, m denotes the length of intersection pixel points between burr extension line and the initial rectangular, M denotes the length between burr extension line and the rectangular boundary. As shown in Figure 4.

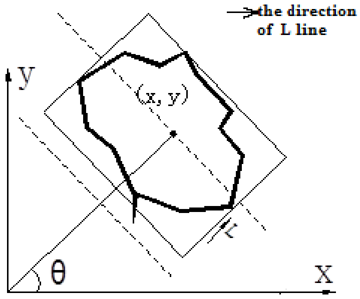


Figure 4. Irregular Graphics with Burr

Based on the intersections' boundary conditions between each extension line and initial rectangular, compare the boundary conditions with the threshold T respectively. If the boundary conditions greater than T, this initial rectangular is the Ferret rectangular. Otherwise, move L1 and L2 in the initial rectangular respectively along the direction vertical to the spindle, and move L3 and L4 along the direction vertical to the secondary axis, stop moving until all the single pixel extension point of the boundary condition and initial rectangular intersecting lines are larger than T, then the Ferret rectangular is obtained.

3. The Morphology of the Skeleton Segmentation

In practice, the road crack is irregular graphic with larger length-width ratio, which is shown in Figure 5.

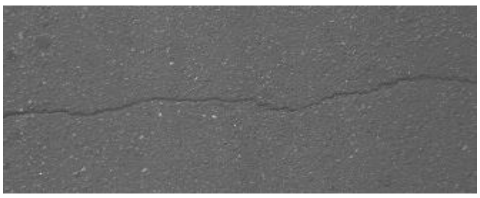


Figure 5. Irregular Crack of Road Surface

If the graphic is sectioned in the longitudinal direction, and the maximum crack width within the subsection is viewed as the crack width, it will greatly improve the accuracy of the crack width measurement. The different section methods will influence the final results. The average section method is that divide the graphic length into several equal subsection and get the width of each subsection. The image changes in the transverse ranges are different which is caused by the irregularity of crack edge contour in each subsection, so the average section method can't applied to all the crack width measurement [9]. In this paper, a section method based on the morphology of skeleton is proposed. It can reduce the measurement uncertainty of the average section method which is caused by not considering the image trend changes.

3.1. Morphological Skeleton Extraction

The image skeleton is defined as the set of all maximum inscribed circle centers in the image. In the Euclidean plane, a point is given randomly in a binary image, and this point is viewed as the center to draw a maximum circle which is inscribed with the image boundary and have at least two points, the given point is the point on the skeleton, and all the centers of the circles consist image skeleton [10]. Its formula of skeleton is as follows [11]:

$$S(I) = \bigcup \{(I \ominus kB) - [(I \ominus kB) \circ B]\} \qquad k = 0,1,2...... \tag{7}$$

Where, I denotes the image, B denotes the structural elements, $(I \ominus kB)$ denotes that it use B to corrode I for K times and it could corrode I to an empty set. If N denotes the final iterations numbers of $(I \ominus kB)$ before I is corroded to an empty set, namely, $N = \max\{k \mid (I \ominus kB) \neq \varnothing\}$, the formula above can be represented as [11-12]:

$$S(I) = \bigcup_{k=0}^{N} \{(I \ominus kB) - [(I \ominus kB) \circ B]\} \qquad k = 0,1,2...... \tag{8}$$

After morphological skeleton extraction, the crack skeleton can be obtained by image de-noising process.

3.2. Boundary-Skeleton Distance Section

The road crack image has been located in the boundary, and divided the boundary into the upper boundary line and lower boundary line, preserve the skeleton graphic in boundary scanning image. $B(x_b,y_b)$ denotes the boundary point coordinate in the binary image I, each pixel point in boundary image is marked by $p \in [1, s]$,s denotes the number of pixels in crack image skeleton. The formula of unilateral boundary-skeleton Euclidean distance in the binary image is shown as:

$$Dis = \begin{cases} \min(d_P(B,Q)) & Q \in S(\mathrm{I}) \\ 0 & \text{others} \end{cases} \tag{9}$$

Here, $d_P(B,Q)=\sqrt{(x_s-x_b)^2 + (y_s-y_b)^2}$ denotes the Euclidean distance between the marked boundary pixel and skeleton, (x_s, y_s)denotes the coordinate of skeleton pixel.

The distance between the skeleton pixel and the upper boundary point is calculated, therefore, for the lower boundary point, the boundary-skeleton distance is shown as the formula:

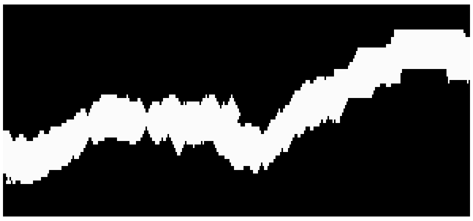
$$D=Dis_{top}+Dis_{bottom} \tag{10}$$

The distribution of boundary-skeleton distance can be obtained based on the above formula. According to the distance distribution, the trend change degree of binary image can be found, and the marked pixels with dramatic distribution change are sectioned. Then measure the width of each subsection image with the improved Ferret rectangular, and find out the maximum width as crack width.

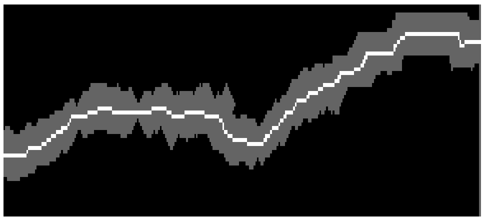
4. The Experiment of the Road Crack Detection

4.1. Experiment Results

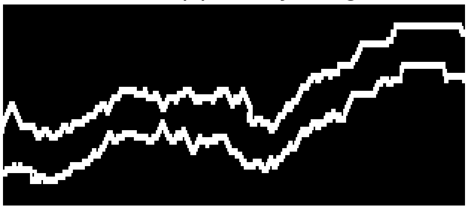
In this paper, the highway road crack image is used as the experimental data. First, we get the binary image of crack image which is shown in Figure 6(a), and get the image skeleton by using the morphological skeleton extraction which is shown in Figure 6(b); then remove the burr of skeleton edge and extract the edge of original image, the edge extraction results is shown in Figure 6(c), the Figure 6(d), shows the retained skeleton image of edge image; then calculate the boundary-skeleton distance, Figure 6(g), shows the distance map; and section the image by using the marked skeleton pixels in the peaks and troughs that shows in Figure 6(e), Figure 6(f), calculates the crack width by the Ferret algorithm.



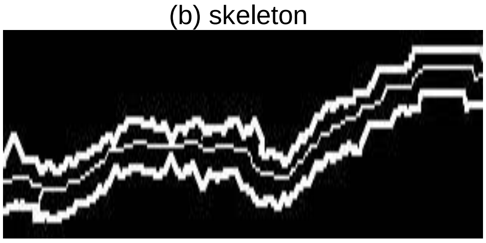
(a) Binary image



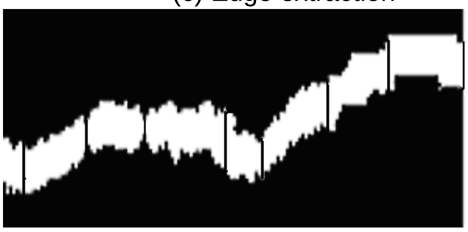
(b) skeleton



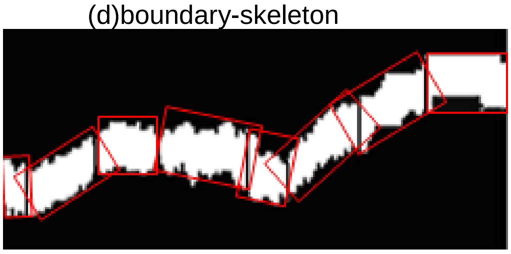
(c) Edge extraction



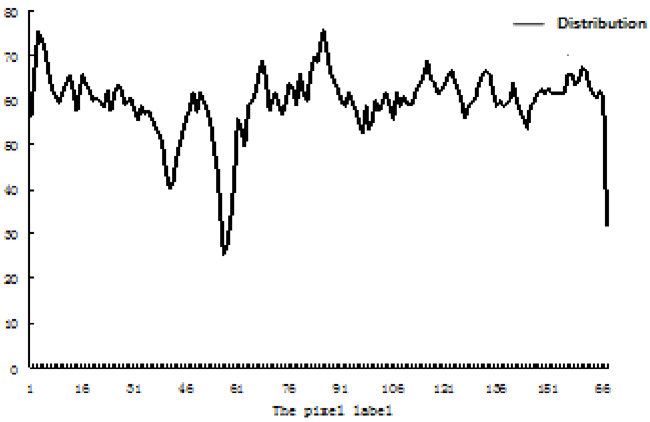
(d)boundary-skeleton



(e) Subsection



(f)Ferret result

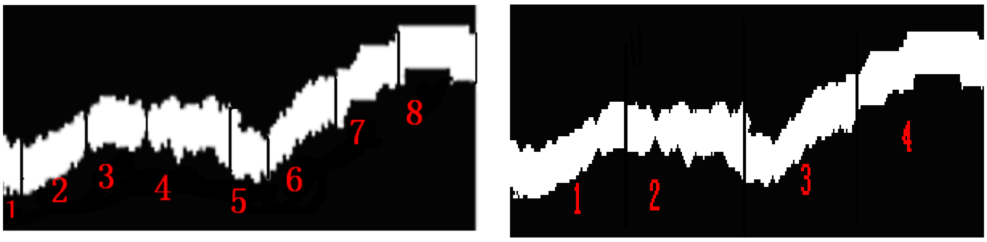


(g)Distance map

Figure 6. Process of Crack Width

4.2. Analysis

In this paper, the pixel of road crack image is 420*128, Figure 7, shows the flag of boundary-skeleton subsection and the flag of average subsection.



(a)Flag based of distance Subsection (b)Flag of average subsection

Figure 7. Flag of Subsection

4.2.1. Width Evaluation: Ellipse algorithm is a common method of measuring the crack width, it can get the accurate measurement results of irregular graphic. So we use ellipse algorithm as a basis for comparison and analysis. The used image pixel is 420*128,choose the flag image 3,4,5,6 and 7 subsection, Table 1, shows the comparison of the ellipse algorithm and the proposed algorithm in this paper.

Table 1. Measurement Results

Label	area/pix	elliptical width /pix	Ferret width /pix	sweep length /pix
3	684	14.34	23.32	20
4	1221	17.12	39.54	35
5	913	17.56	26.49	23
6	2596	21.89	38.46	41
7	1961	23.46	35.21	33

As it can be seen in Table 1, the effect of these two methods is similar under the situation of subsection, but for the graphic with large length- width ratio, for example, subsection 4 and subsection7, the Ferret width measurement method is closer to the actual scanning results than ellipse algorithm. It means that the Ferret method is more suitable for road crack detection with large length-width ratio in practice.

For the measurement of edge crack image with burr but can’t remove, which is shown in Figure 8, (the 4 subsection of Figure 7 (a)), the Ellipse algorithm will cause great measurement error due to the limitations of radius values. By analyzing a large number of experimental results, the value of T is 5%-6%，the rectangular length in Figure 8, is 38.23, the pixel numbers of intersection point are 2.21, τ =5.8%, the crack width is 39.54, the crack width using Ellipse algorithm is 17.12, and the scanning crack width is 35. There is no other algorithm can solve the problem of road surface boundary roughness, the existence of burr when measure the crack width at this stage, so the algorithm in this paper is of certain significance in practical application.

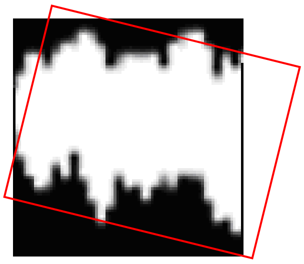


Figure 8. Ferret with Edge Condition

4.2.2. The Evaluation of Valuable Information: In general, the background pixels in crack image are usually seen as useless information, the distribution of the useful crack pixels is related to the quality of crack detection. So the subsection accuracy is determined by the ratio of crack pixels distribution and background useless information.

$$H_I = \frac{\sum_{i=1}^{n} h_i s_i}{\sum_{i=1}^{n} s_i} \tag{11}$$

Where, H_I denotes the utilization of the effective information, h_i denotes the ratio of pixels number between the subsection crack region and the Ferret rectangular, s_i denotes the area of i subsection. The effective information of weighted average can be used to evaluate the advantage and disadvantage of section. The bigger the value of H, the more useful information there is, the better of section effect. Vice versa. Table 2, and Table 3, are respectively the percent of valuable information based on average subsection and distance subsection

Table 2. Percent of Valuable Information Based on Average Subsection

label	h_i	s_i	H_I
1	0.56	1964	0.676
2	0.66	2788	
3	0.59	3438	
4	0.87	2964	

Table 3. Percent of Valuable Information Based on Distance Subsection

label	h_i	s_i	H_I
1	0.73	301	0.844
2	0.86	1326	
3	0.87	769	
4	0.69	1632	
5	0.89	1023	
6	0.92	1621	
7	0.81	2423	
8	0.93	1059	

The subsection method should be used in the position with large crack trend change. According to the analysis of experimental results in the table above, the information utilization of subsection method based on boundary-skeleton distance is better than the average subsection. It means that the boundary-skeleton distance method is more accurate to measure the crack width.

5. Conclusion

The crack width detection of road surface is an important aspect of road detection, which is related to the traffic safety. The method based on digital image can improve the work efficiency and reduce the error.

In this paper, we propose a crack width measurement based on the second moment Ferret according to the feature of the crack. According to the experimental results, the Ferret algorithm with boundary conditions can solve the inaccurate measurement problems of crack width caused by the unsmooth of crack edges. The distance subsection method based on boundary-skeleton can solve the problems of inaccurate measurement in practice.

Compared with the traditional manual method, the proposed method can eliminate the influence of human factors and get more accurate results. However, in practice, crack depth is also an important criterion for road damage evaluation, which is an important research direction for the use of 3D laser technology in the future.

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Authors

Liu Sheng, lecturer in information engneering. She obtained her Ph degree in 2015 at School of Information Engineering, Chang'an University,China.Her interests involve image processing and analysis, pattern recognition and computer vision.

Wang Weixing, professor in information engineering. He obtained his PhD degree in 1997 at Royal Institute of Technology in Sweden, since 2001, he has been a PhD supervisor at Roy al Inst ituet of Technology, now he is a visiting professor at Chang'an University, and his interests involve information engineering, image processing and analysis, pattern recognition and computer vision.3

Wang Fengping, PhD student at School of Information Engineering, Chang'an University, China. Her current interests are in the areas of feature extraction in remote sensing images, image processing and analysis, and computer vision.