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ROAD DAMAGE IDENTIFICATION AND DEGREE ASSESSMENT BASED ON UGV

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Abstract- Aiming at the problem of automatic identification and evaluation of road damage degree, the road damage identification and degree assessment algorithms based on unmanned vehicles experimental platform are studied. The road crack segmentation extraction method based on adaptive sliding window is studied. On this basis, the road damage crack classifies and identifies according to the crack geometry information and the principle of template matching. The road damage degree assessment algorithm based on fuzzy decision is proposed based on the quantitative analysis of the road crack and the corresponding parameters information. The experimental results demonstrate that the road damage identification and degree assessment algorithms proposed in this paper are effective and stable.

Index terms: unmanned vehicle, damage identification, quantitative analysis, fuzzy decision

I. INTRODUCTION

With the rapid development of social economy in China, the national road traffic mileage continues to increase substantially. According to the latest statistics, China has become the world's largest car market since 2009. The numbers of car are 104 million which occupied 10% of the world's car ownership. It is a pressure and challenge for our country’s road maintenance and management work with so many cars on the road and a substantial increase of our road.

With the rapid development of computer technology and image processing technology [1, 2], the identification technology based on the digital image of road damage has attracted more and more attention. Compared with the traditional manual detection identification technology, the identification technology of road damage based on image recognition technology can identify the damage road pavement quickly, efficiently and accurately. The identification technology of road damage does not affect the normal road transportation and saves a lot of work force, material resources, which make the road maintenance strategy more scientific and reasonable. Chun Jung Hsu uses moment invariants as pavement image features to identify road damage. With the increase of the order number moment, the Chun Jung Hsu’s algorithm becomes sensitive to noise, and contains much redundant information [3]. H. d. Cheng uses morphology method to process the road damage images. H. d. Cheng’s algorithm describes the road damage image by extracting geometric features such as pavement disease intersection n, area, perimeter, and disease areas. The effect of H. d. Cheng’s algorithm is good. However, the processing time is longer than the other algorithms [4]. According to the histogram differences between the transverse crack and the longitudinal crack in the vertical direction and horizontal direction，Bayoung Jik Lee identifies the longitudinal crack and horizontal fractures accurately. However, the turtle shaped crack recognition rate of the Bayoung Jik Lee’s algorithm is low [5]. Taking area and damaged area perimeter as input characteristics of a turtle shaped cracks; Xiong Hejin carries out massive cracks classifier and quantitative analysis on the turtle cracks and massive cracks [6]. Xiao Wangxin proposes a new pavement damage evaluation and classification method based on the broken density factor [7]. Xiao Wangxin’s algorithm has good effects in translation invariant, rotation invariant and pavement damage degree. Ding Ailing studies on the damage crack classification method based on support vector machine [8]. The cracks are classified based on the optimum parameters determined by the principle of optimal classification.

In this paper, the road crack segmentation extraction method based on adaptive sliding window is studied. On this basis, the road damage crack classifies and identifies according to the crack geometry information and the principle of template matching. The road damage degree assessment algorithm based on the fuzzy decision is proposed based on the quantitative analysis of the road crack and the corresponding parameters information. The algorithm proposed in this paper has good real time characteristics and good experimental results, which provides a scientific basis for road damage classification.

II. ROAD CRACK IMAGE PROCESSING

The road crack image-processing algorithm shows in Figure 1. Crack image should be preprocessed, including format conversion, gray, gray level change, smoothing, sharpening processing [9]. Then the crack segmentation in the preprocessed image is extracted. According to the obtained quantitative parameters of the crack and the principle of template matching, the crack can be classified with the least squares method.

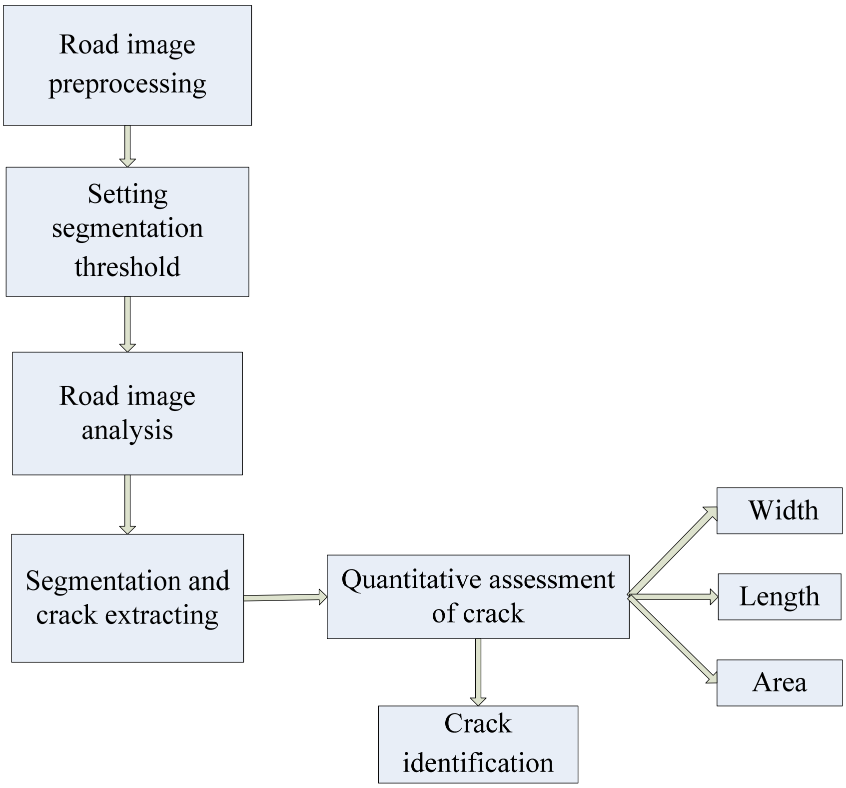

Figure 1. The processing algorithm of road crack image

2.1 Segmentation and extraction of crack

The segmentation threshold should be set before the road damage images segmented. By adjusting the binary dynamic threshold and observing the binary image of the road damage image, the threshold can be determined. Then the threshold passes to the function modules of the segmentation image. The criteria to determine the threshold is: (1) the texture of the image surface in display is clear. (2) When the edge profile is intact, the dark area of mirror surface is relatively dark except for a few interference or noise. Then binary threshold value can be determined and used as a segmentation threshold of the image segmented.

When the threshold is determined, image segmentation performed. Observing road damage image, it is not difficult to find that the background texture of road damage image is brighter (grey value is higher), and the area in the image is larger. The crack texture may be darker (gray levels is lower), and the area in the image is relatively small. Therefore, based on the differences of image texture, the image segmentation can be achieved by comparing the grey value and size. In this paper, the image segmentation algorithm based on adaptive sliding window is studied to remove the background texture. The specific operation steps are as follows:

(1)The image resolution collected by image acquisition system of UGV is 1280×960 and the size of window is 10×10;

(2) A memory array named M with the same size as image memory is established, and the initial value is set to store the image texture information;

(3) Half the length of the window takes as the step-moving window. The mean gray level within the window achieves.

When the gray value of the area the window moves is greater than the segmentation threshold, the gray level information value of the corresponding M array changes to indicate that the corresponding background image texture needs to remove.

(4)The crack image textures segment according to the information of M array when the window has moved to the end of the image. Then the process of road image analysis is performed. The details in the collected road damage images are highlighted based on the edge detection algorithm, and the blurred details are enhanced to protrude the edge information. The analysis process of the road image is determined by the image texture and crack edge information. In order to obtain a better edge detection result, Gauss-Laplace operator is adopted in this paper. Gauss-Laplace operator combines Gaussian smoothing filter and Laplace edge sharpening filter together to smoothly filter out noise and then detect the edge.

After analyzing the images, all of the edge information of the image is obtained, including the image texture and the edge information of road damage image. Then the texture information of road damage image needs to be segmented and extracted. The realization process is as follows: an array of memory obtains from the image segmentation method; the memory array is matched to the memory array with only edge information of road damage image to eliminate the edge information that belongs to the image texture information and leave only the edge of the crack.

2.2 The identification of road damage

The work of damage identification mainly consists of three stages. The first stage is the crack segmentation, that the crack is extracted from the road damage image to make it separate from background. Image segmentation belongs to this step. The second stage is the feature extraction and selection. Various aspects of crack will be measured to get a set of features named a group of characteristic vectors $X = (X_1, X_{2,}, X_{3,} \cdots, X_n)$. In this article, the geometrical characteristics such as area, width and length are selected. The third stage is the most important stage. The crack identification task is completed based on the optimal decision classification, namely the target (crack). The segmented image that meets the crack characteristics are taken to match the template to find all points that belongs to the entire crack.

Template matching refers to using a smaller template to compare with the source image to find out whether there is the same or similar area as the source images. If there is this kind of area, its position is determined and the region information is extracted. The error sum of square of the template and original image corresponding area is commonly used as a measure of template matching. Assuming that $f(x, y)$ is the original image whose size is $M \times N$ and $t(j,k)$ is a template whose size is $f(x, y)$. The error sum of square is defined as formula (1):

$$D(x,y) = \sum_{j=0}^{J-1} \sum_{k=0}^{K-1} [f(x+j, y+k) - t(j,k)]^2 \quad (1)$$

Formula (1) is commenced as follows:

$$D(x,y) = \sum_{j=0}^{J-1} \sum_{k=0}^{K-1} [f(x+j,y+k)]^2 - 2\sum_{j=0}^{J-1} \sum_{k=0}^{K-1} f(x+j,y+k)t(j,k) + \sum_{j=0}^{J-1} \sum_{k=0}^{K-1} [t(j,k)]^2 \quad (2)$$

Make

$$DS(x,y) = \sum_{j=0}^{J-1} \sum_{k=0}^{K-1} \left[f(x+j, y+k) \right]^2$$

$$DST(x,y) = 2\sum_{j=0}^{J-1}\sum_{k=0}^{K-1} f(x+j, y+k)t(j,k)$$

$$DT(x,y) = \sum_{j=0}^{J-1}\sum_{k=0}^{K-1}\left[t(j,k)\right]^2$$

$DS(x,y)$ refers to the area energy in the image corresponding with the template. $DS(x,y)$ is associated with pixel location (x,y) .With the change of the pixel (x,y), the $DS(x,y)$ also slowly change; $DST(x,y)$ is the cross-correlation between the template and the original image corresponding region, which changes with the pixel (x,y) position slowly; When the corresponding area of the template matches with the image, the $DST(x,y)$ is the maximum value; $DT(x,y)$ is called energy template. The $DT(x,y)$ value is constant and just needs to be calculated once.

Based on the above analysis, assuming that $DS(x,y)$ is a constant, template matching is only related to $DST(x,y)$ .When $DST(x,y)$ is the maximum value, the corresponding area of the template and image is matched. Therefore, a match threshold should be set. When the value of $DST(x,y)$ is larger than the match threshold, the corresponding area of the template and image is matched. The pixel location (x,y) is recorded and deposited in the array in NA.

After the crack pixel location information is stored in the array of NA, these discrete crack points are classified. Points belonging to the same crack are put together. The crack locations of the start and the end are saved.

These discrete points are categorized with the eight adjacent point spread method. In digital image, a pixel may be very close to a number of other pixels in the space. In the digital image expressed in a grid, a pixel has a common boundary and shares the vertex with the other four pixels. If two pixels have a common boundary, that is to say they are four adjacent points. Similarly, if two pixels share at least one vertex angle, that is to say they are eight adjacent points. A pixel has 4 connected relationships with its four adjacent points and 8 connected relationship with its eight adjacent points. The rectangular pixel networks of four adjacent points and eight adjacent points are shown in Figure 2.

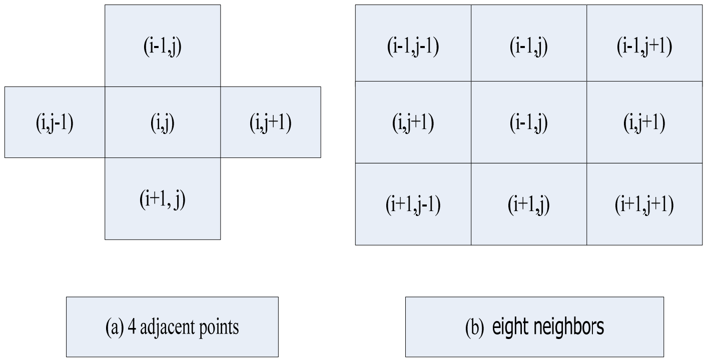

Figure 2. 4 adjacent points and eight neighbors

The identification algorithm process of road damage is as follows:

(1) Take the first point “a” in the array of NA, the point and the eight adjacent points are stored in the array of EA. Then remove the “a” point from the NA.

(2) Found out and named points through the array in the eight adjacent points of “a” point as “b”. The point “b” and its eight adjacent points are also stored in the EA. The “a” and “b” points are stored in a crack array SameNick. Remove point “b” from the NA.

(3) Step (s2) is repeated until all of the points belonging to A crack are founded.

(4) When the crack points belonging to A crack finish classification, the A crack is quantized to determine the start and end points. Then the information of A are stored in a temporary array.

(5) Repeat the above steps until all points in the NA are removed. The classification is completed.

After the pixels belonging to the same crack are divided into an array, the start and end pixels of the crack are founded. When the start pixel point and the end pixel point are the same, it can be divided into turtle crack according to the characteristics of turtle crack. When the end is different from any other pixels on crack, the curve can be fitted with the method of least squares. Least squares method is a kind of mathematical optimization techniques proposed by Gauss. It obtains the best matching function data by minimizing the error sum of square. According to the characteristics of the crack, pixels belonging to the same crack scatter in a straight in line with the least squares linear function model, namely:

$$y_j = kx_j + b \quad (3)$$

Wherein, K represents slope; b represents an arbitrary real number. According to the value of the slope k, the crack can be identified. While the cracks that cannot fitted to a straight line can be classified according to the turtle crack. In order to determine the value of k, according to the principle of least square method, the actual coordinate pixels on the crack are (x_i, y_i). n represents the number of pixels on the crack. Making $\varphi = \sum (y_i - y_j)^2$, formula (4) can be achieved according to formula (3).

$$\varphi = \sum (y_i - kx_j - b)^2 \quad (4)$$

The partial derivative of k and b are obtained respectively. The two partial derivatives are made equal to zero, namely:

$$\sum y_i = nb + k \sum x_i \quad (5)$$

$$\sum x_i y_i = b(\sum x_i) + k \sum x_i^2 \quad (6)$$

Formula (5) and (6) are the two equations about k and b. The follow formula (7) can be obtained by solving Formula (5) and (6) :

$$k = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{m \sum x_i^2 - (\sum x_i)^2} \quad (7)$$

According to the calculated values of k, the crack can be identified. If the k value is less than 1, the crack is classified as transverse crack. If the value of k is greater than or equal to 1, the crack is classified as longitudinal crack.

2.3 Defect quantifying

Carry out quantitative analysis on the road crack, which is based on the perspective of the geometrical characteristics of the crack. The related parameters of crack are calculated. For transverse cracks and longitudinal crack, the length and width are calculated. For the turtle crack, its area is calculated.

(1)The calculation method of crack length

The crack edge of the transverse or longitudinal collected is irregular and the bending degree is not the same in each paragraph. In order to simplify the calculation process, the transverse crack or longitudinal crack need to be refined. As the method that the transverse crack and the longitudinal crack are treated and calculated are same, this article only gives one kind of calculation process of transverse crack, for example.

1) Open operation is carried out on the transverse cracks image, so that the interference points in the crack region and background region are eliminated and the edge of the crack is refined. In addition, the small burrs at the edge are removed; closed operation is carried out on the transverse cracks image, so that the edge of small space and connected tiny cracks are filled. After the

continuous open operation and close operation are taken to transverse crack image, it is not difficult to find out that the edge of crack gets smooth and crack image has been effectively improved.

2) The structural element sequence is $\{M\} = \{M^1, M^2, M^3, M^4, M^5, M^6, M^7, M^8\}$. Elements of each structural element sequence are shown in Figure 3. The shaded area represents 1, and white areas represent 0. Crack binary image are divided according to the formula (8):

$$A \otimes \{B\} = ((\cdots((A \otimes B^1) \otimes B^2) \cdots) \otimes B^n) \quad (8)$$

Wherein, A represents image collection, B represents structural element sequence.

3) After refining the crack collection by each element in a structural element sequence, repeat this process until the result is no longer change any more.

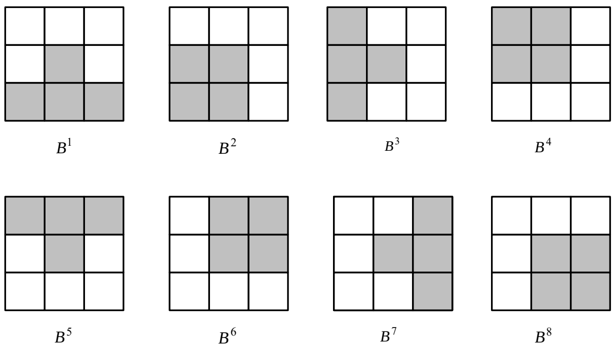

Figure 3. Structural element sequence of construct

4) The results of the step 3) are converted to m connected set of detail to eliminate multiple paths.

5) The two adjacent pixels of the crack is represented as (m_{i+1}, n_{i+1}) and (m_i, n_i). k represents the actual length corresponding to unit pixel. Moreover, the distance between them represents as:

$$l = k \times \sqrt{(m_{i+!} - m_i)^2 + (n_{i+1} - n_i)^2} \quad (9)$$

So, the whole crack length is as in formula (10):

$$L = \sum_{i=0}^{T-1} k \times \sqrt{(m_{i+1} - m_i)^2 + (n_{i+1} - n_i)^2} \quad (10)$$

Wherein, T represents the number of crack pixels.

(2)The calculation method of crack width

When the crack width is calculated, taking into account that damage degree of the crack is evaluated by fuzzy evaluation algorithm in this paper, just the average crack width needs to be calculated. Assuming the starting point pixel of the crack is (m_0, n_0) and the end pixel is (m_i, n_i), then the mathematical calculation formula of the average width is:

$$W = S \Big/ k\sqrt{(m_i - m_0)^2 + (n_i - n_0)^2} \quad (11)$$

Wherein, W represents the average width of crack. S represents area of the crack area. The Euclidean distance of the start and end is calculated by $\sqrt{(m_i - m_0)^2 + (n_i - n_0)^2}$.

The length and width of crack are calculated, so that the severity of the crack can be more accurately understood. The road can be repaired timely. The manual inspection of imperfect can be eliminated [10,11].

(3)The calculation method of crack area

The calculation of crack area mainly aims at the breakage of turtle crack or blocks crack. Before the creak area of the turtle crack is calculated, the crack image is processed by using continuous open and close operation to improve the crack image. According to the feature that the crack image information processed is binary image, it can be known that the pixel value of the background region is 0 and the pixel value of the crack area is 1. Therefore, the edge of the turtle crack area is extracted. Then the numbers of pixel within the boundaries are counted. Finally, the number of the pixels whose value is 1 and the number of pixels within the boundary are added. The area of turtle cracks is obtained by multiplying the sum and the area of each pixel.

The boundary of turtle crack binary image is extracted by formula (12):

$$\beta(A) = A - (A \Theta B) \quad (12)$$

Wherein, $\beta(A)$ represents the boundary of the crack. A represents the crack collection. B is a suitable structural element.

The crack set A is traversed by the structure element B from left to right and from top to bottom. The diagram of boundary is shown in Figure 4.

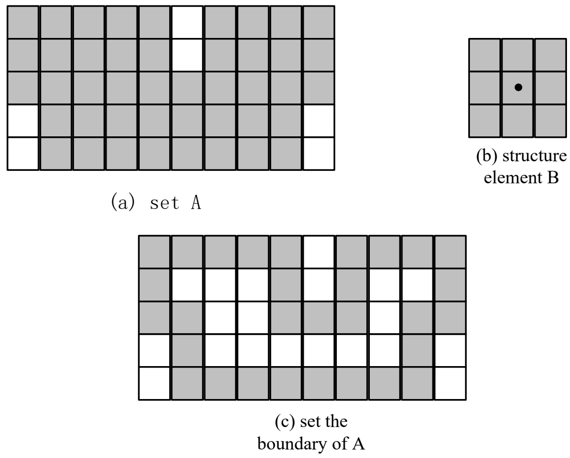

Figure 4. Boundary extraction diagram

In Figure 4, (a) is binary image to be processed. The shaded areas represent the crack area and the white areas represent the background. (b) represents the structure element B. Boundary diagram extracted is shown in Figure (c).

III. FUZZY EVALUATION OF ROAD CRACK

Fuzzy evaluation [12, 13] is based on the fuzzy mathematical model, which should be considered respectively from two aspects of single index and multiple indexes. The construct of single measure function of index attribute and membership function are different. The first j measure function of index attribute is constructed by attribute mathematical model $\mu_{xjk}(t)$. The membership function is constructed by fuzzy mathematical model. The former meets the additive, while the latter does not necessarily meet the additive.

The multi-index comprehensive results are different. Attribute measure should meet the target that the measure sum is 1. However, the sum of membership degree of fuzzy mathematical model should be 1. It is difficult to construct a reasonable membership function.

The road damage level is mainly determined by the following three indicators: (1) horizontal crack; (2) longitudinal crack; (3) turtle crack. Wherein, each of the indicators is subdivided into several sub-indexes. The evaluation index of road damage is shown in Table 1:

Table 1: Evaluation index of road damage

Evaluation index	**The sub index**
Transverse cracks	length, width, the number of crack
The longitudinal crack	length, width, the number of crack
Turtle crack	area

The road damage image is processed properly to obtain the quantitative evaluation indexes. Then the results of road damage level can be obtained according to the given attribute comprehensive evaluation system.

Transverse crack can be considered by relevant experts to specify a scoring criterion. The horizontal crack section is divided into two small targets. Each index has digitized evaluation results. The division of longitudinal crack and turtle crack part can refer to the transverse crack parts.

The object of study space is set to be X= {All kinds of road crack damage digital image collection}. The attribute space is set to be F= {Damage level}. The damage level F can be divided as six levels:

C1={Without damage}; C2={Slightly damaged}; C3={Slightly damaged}; C4={ Moderate damage }; C5={Severe damage }; C6={Serious damage}.

Regulation: C1>C2…C5>C6

The transverse crack part：I1={Length}，I2={Width}. The transverse crack index hierarchy of road damage is shown in Table 2.

Table 2: Transverse crack index hierarchy of road damage Unit： *mm*

	C_1	C_2	C_3	C_4	C_5	C_6
I_1	0	0~2	2~4	4~6	6~8	8~10
I_2	0	0~500	500~1000	1000~1500	1500~2000	2000~2500

The longitudinal crack part: I1= {Length} and I2={Width}. The longitudinal crack index hierarchy of road damage is shown in Table 3.

Table 3: Longitudinal crack index hierarchy of road damage Unit： *mm*

	C_1	C_2	C_3	C_4	C_5	C_6
I_1	0	0~2	2~4	4~6	6~8	8~10
I_2	0	0~500	500~1000	1000~1500	1500~2000	2000~2500

Turtle crack part: I= {Area}. The turtle crack index hierarchy of road damage is shown in Table 4.

Table 4: Turtle crack index hierarchy of road damage Unit： mm^2

	C_1	C_2	C_3	C_4	C_5	C_6
I	0	0~400	400~800	800~1200	1200~1600	1600~2000

Referring to the properties of individual indicators formula, the various individual indicators attribute measure function is calculated as below. The attribute measure formula of transverse cracks is given, similar to other.

$$\mu_{x_{11}}(t)=\begin{cases}0 & t>1\\ 1-t & 0<t<1\\ 1 & t=0\end{cases} \quad (13)$$

$$\mu_{x_{12}}(t)=\begin{cases}0 & t>5\\ t & 0<t\le 1\\ \dfrac{t-1}{2} & 1<t<3\\ 0 & t=0\end{cases} \quad (14)$$

$$\mu_{X_{13}}(t)=\begin{cases}0 & t>7\\ \frac{3-t}{2} & 1<t<3\\ \frac{5-t}{2} & 3\le t<5\\ 0 & t<3\end{cases} \quad (15)$$

$$\mu_{X_{14}}(t)=\begin{cases}0 & t>9\\ \frac{t-3}{2} & 3<t<5\\ \frac{t-5}{2} & 5\le t<7\\ 0 & t<5\end{cases} \quad (16)$$

$$\mu_{X_{15}}(t)=\begin{cases}0 & t>11\\ \frac{7-t}{2} & 5<t<7\\ \frac{t-7}{2} & 7\le t<9\\ 0 & t<7\end{cases} \quad (17)$$

$$\mu_{X_{16}}(t)=\begin{cases}0 & t>13\\ \frac{9-t}{2} & 7<t<9\\ \frac{t-9}{2} & 9\le t<11\\ 0 & t<9\end{cases} \quad (18)$$

IV. THE EXPERIMENT AND ANALYSIS

This article adopts the unmanned vehicle, AS-R intelligent mobile robot that is produced by the future partner in Shanghai Limited Company. As shown in Figure 5. AS-R uses wheel drive and modular design with the standard of sonar, voice, image and other many kinds of sensors. It is convenient for various extensions.

Figure 5. AS-R intellective robot

According to the advantages of modular, the road damage degree identification and assessment system based on UGV are modular processed. The degree of road damage identification and evaluation system based on UGV includes four modules, which are respectively damage road image preprocessing module, road damage recognition module, the quantitative analysis of crack and damage degree assessment module. The specific structure of the distribution is shown in Figure 6. Among them, the road damage image must be processed by the road damage image-preprocessing module. The damage degree assessment module is executed based on crack quantitative analysis module.

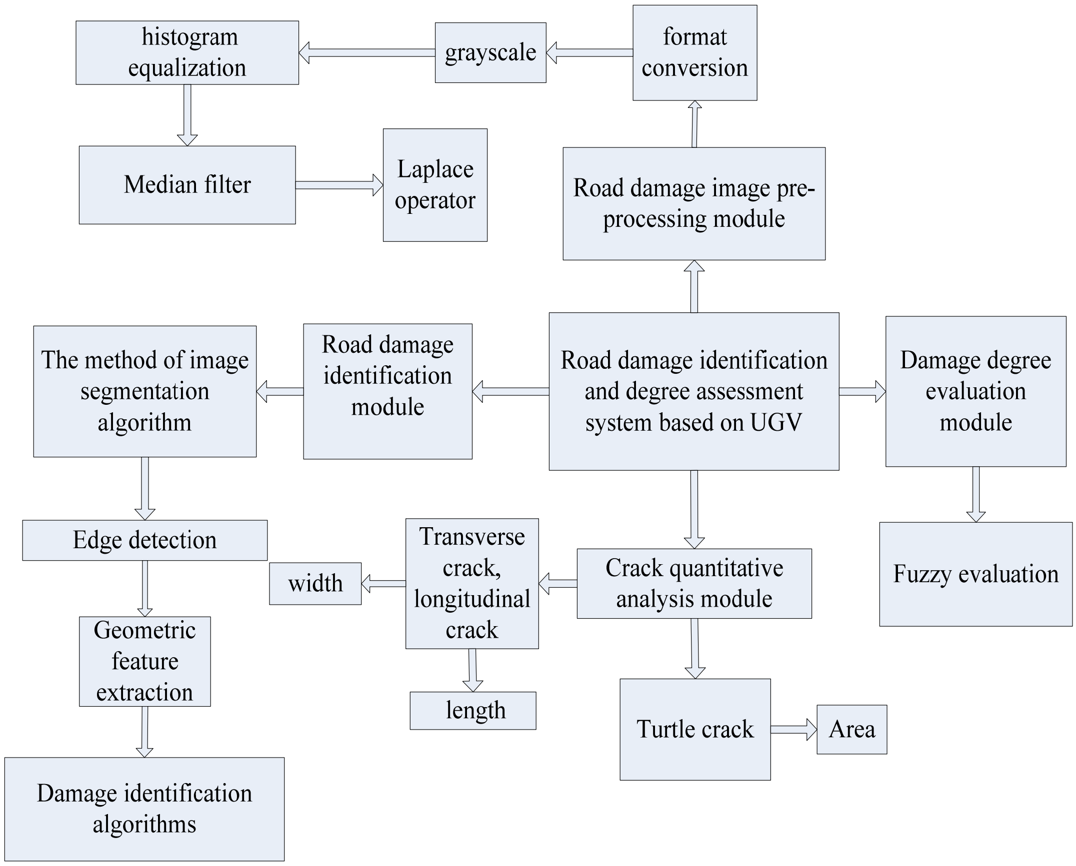

Figure 6. Function modules of the road damage degree recognition and assessment system

The road damage recognition software system is designed and studied based on the characteristics of crack damage. The images used in the experiment are shown in Figure 7.

Figure 7. Images used in the experiment

The transverse cracks and damage degree evaluation results of longitudinal cracks are shown in Table 5. The turtle crack damage degree assessment results are shown in Table 6. It can be seen from Table 5 and Table 6 that the identification algorithm and degree assessment algorithm are effective and stable.

Table 5: Transverse cracks and damage degree assessment results of longitudinal cracks

Damage types	**Number**	**Damage degree**
Transverse cracks	0	Slightly damaged
	1	Slightly damaged
	3	Moderate damaged
	4	Severe damage
	1	Serious damage
Longitudinal crack	0	Slightly damaged
	1	Slightly damaged
	3	Moderate damaged
	2	Severe damage
	0	Serious damage

Table 6: Turtle crack damage degree assessment results

Damage Types	**Number**	**damage degree**
turtle crack	0	Slightly damaged
	0	Slightly damaged
	1	Moderate damaged
	1	Severe damage
	0 severe	Serious damage

V. CONCLUSIONS

In this paper, the degree identification of road damage and assessment technology is studied based on the unmanned vehicle. The related software based on Visual $c++$ development platform is designed. The road damage identification and degree assessment algorithms proposed in this paper can provide important scientific basis for maintenance departments. However, due to time and other objective factors, there are some drawbacks for the degree identification and assessment technology of road damage based on the vehicle system in this paper. The system needs to be further improved. The focus and direction for the future research should focus on the following aspects:

The types of road damage are divided into road pavement damage type crack, mending, pit slot, show defects, surface deformation and damage of hybrid. This paper studies the crack damage. Research should be made for other types of work and carry on comprehensive evaluation in the next step.

VI. ACKNOWLEDGMENT

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