Study on Pavement Defect Detection Based on Image Processing Utilizing UAV

Lei Zhang1*, Weichi Xu2, Leilei Zhu3, Xiaozhe Yuan1, and Chuang Zhang2
1 Intelligent Transportation System Research Center, Southeast University, Corresponding Author, Nanjing 210096, China
2 Transportation College of Southeast University, Nanjing 210096, China
3 Highway Agency, Department of Transportation of Jiangsu, Nanjing 210004, China
*Corresponding author’s e-mail: lei800@163.com

ABSTRACT: With the continuous expansion of traffic volume in China, pavement deterioration recognition is a key technique to reflect the real state of the roads and to provide the basis for decision of the maintenance plan. In this paper, a new pavement defect detection system based on Image Processing was developed which utilized Unmanned Aerial Vehicle (UAV) to avoid blocking the traffic flow and to enlarge monitoring range. It was divided into two subsystems: UAV intelligent control modulus and defect detection modulus. For the former, special programs were designed to achieve the functions such as automatically taking off and landing, automatically trajectory control, and camera and gimbal control. For the latter, based on the comparative analysis of the basic principles and multiple image groups experiments of normal edge detection algorithms, a combined method was proposed. This proposed method can not only automatically provide the high threshold that Canny algorithm needs to input manually, but also solve the lack of edge detection ability in OTSU segmentation algorithm. The efficiency and accuracy of the image processing is verified through the experiments. It is also showed that the weak edges in the image can be better retained by taking 1/3 to 1/2 of the high threshold as a low threshold in this combined method. According to both qualitative and quantitative analysis, it can be concluded that, among the normal algorithms taken into study, the proposed combination algorithm performs best in terms of recognition accuracy of crack types and crack geometry features extraction.

1. Introduction
Highway is an important infrastructure, which will promote the social economy development and make the transportation system more convenient and reliable. However, vehicles running on the road will inevitably cause damage of the pavement. If the road is working continuously in a state with medium or severe level of the pavement damages, the service life will be significantly shortened, and the maintenance costs will also be greatly increased. Therefore, pavement defects detection and monitoring are very important as to evaluate the real working state of the highway infrastructure and to find feasible maintenance plan. It is a key issue to develop a new detection method which could not only provide timely and accurate results but also avoid blocking the traffic flow.

With the development of image acquisition and image processing technologies, automatic monitoring systems for pavement defects has also been developed and applied[1], such as normal imaging technology[2], analogy video technology[3], Charge-coupled Device (CCD) imaging, and those based on line scanning camera[4]. However, the above methods more or less have problems...
such as low accuracy, high cost and low efficiency, which will have negative effects on the practical application. Moreover, those methods are generally applied on Vehicle Mounted System, which may be influenced by the roughness condition, shadows of vehicles and trees nearby, and another disadvantage is the small coverage of the road surface area.

In this paper, a new system using Unmanned Aerial Vehicle (UAV) was developed to eliminate the aforementioned disadvantages with modules of UAV intelligent control, preprocessing of defect images, edge detection of defect images, defect positioning and classification, and feature extraction. This scheme realizes automatic detection and recognition of pavement defects and proposes new operation methods for edge detection algorithms, which improves the accuracy and efficiency of automatic detection and establishes the basis for large-scale application of automatic defect detection in practice.

2. System Components

In this study, the Unmanned Aerial Vehicle (UAV) was employed as a camera carrier, thus, a set of UAV intelligent control programs were composed to ensure the camera position and shooting angel. The main components of the system contain the DJI UAV M100, Onboard-SDK-ROS-3.2 (Software Development Kit), Manifold (embedded computer). Based on the Linux system, the flying control module was coded through the DJI SDK. And monitoring procedures was embedded in it to achieve automatic and real-time photographing with high efficiency. The framework of the system is shown in Figure 1:

- UAV intelligent control system. UAV intelligent control system is mainly divided into two parts, i.e. flying control and camera control to better meet the defect detection function[5];
- Defect image preprocessing. The image preprocessing is realized by image grayscale conversion, image filtering process, image sharpening and image grayscale stretching.
- Defect recognition. Pavement defects such as cracks, potholes and patches, are some kind of edges. Therefore the edge detection was first conducted and then defects were figured out from the detected edges. Different image edge detection algorithms were studied and compared considering the basic mathematical principles, the recognition rate, computation efficiency, and so on. Based on it, a combined method was proposed for the system.
- Defect positioning, defect classification and feature extraction. Morphological operation was carried out on the result of edge recognition to refine the defect accurately. Based on the relationship between the lengths of the projection in the x and y directions and the pixels in the defect region, the features such as area and length were extracted.
As an example, the case study only focused on the identification of pavement cracks, while neglecting the potholes and rutting[6] which need to be identified by three-dimensional reconstruction. And three main types of cracks were considered, which are the horizontal crack, longitudinal crack, and alligator crack.

3. Comparison Study

3.1 Qualitative analysis

The accuracy and efficiency of the crack identification largely depend on the selection of the edge detection algorithm. The popular algorithms including Sobel[7], Canny[8], LoG[9], OTSU[10], and Local adaptive threshold[11] were taken into study and were checked based on 100 typical images comprised of cracks. In this study.

Table 1. Comparison on the Crack Recognition Effects by Different Edge Detection Algorithms

| Item                              | Horizontal cracks | Longitudinal cracks | Alligator crack |
|-----------------------------------|-------------------|---------------------|-----------------|
| Original images                   | ![Image](image1)   | ![Image](image2)    | ![Image](image3) |
| Canny edge detection             | ![Image](image4)   | ![Image](image5)    | ![Image](image6) |
| OTSU edge detection              | ![Image](image7)   | ![Image](image8)    | ![Image](image9) |
| Local adaptive threshold method   | ![Image](image10)  | ![Image](image11)   | ![Image](image12) |
| Proposed combination algorithm    | ![Image](image13)  | ![Image](image14)   | ![Image](image15) |

These pictures were categorized into 12 groups according to the types of cracks (horizontal cracks, longitudinal cracks, and alligator cracks etc.), the types of pavement (mixture) and the lighting conditions (bright and dark). For the detection algorithms that need initial threshold input, a sample of each group was randomly selected to obtain corresponding threshold for each group, respectively. In addition, for Canny algorithm in which two thresholds were needed as input parameters, combinations of different high threshold and low threshold were studied. The result indicated that when the high threshold is 2 - 3 times of the low threshold, Canny algorithm could identify the pavement cracks better. As example, typical image of each class including the horizontal cracks, longitudinal cracks and alligator crack, was picked to conduct qualitative analysis, and some results were listed in Table 1.

The comparison of the edge detection resulted from those 100 images indicated that the LoG edge detection, which used the second order derivative, was very sensitive and influenced greatly by the noise. Another reason for it is suitable for the image-based automatic defect recognition system, is that the outline of the pavement particles was often identified as part of cracks. Recognition mainly rely on image edge detection technology, therefore, the accuracy of edge detection is directly related to the
effectiveness of defect identification. Sobel edge detection and Scharr filter edge detection tended to form false edges, which would have a great impact on subsequent processing, so both the algorithms are also not suitable for automatic pavement defect recognition system. Although Canny edge detection required manual input thresholds, it worked well for pavement cracks. Despite the OTSU has some disadvantages such as less effective segmentation and easy to be affected by noise, it can adaptively find the segmentation threshold corresponding to the image grayscale. Therefore, the two algorithms were combined and noted as Proposed Combination Method. The threshold value generated by OTSU algorithm can be used as the high threshold value for Canny edge detection. The method of local adaptive threshold had good effect on edge detection. So it can also be used as one potential algorithm for automatic defect detection. The above comparison results were mainly based on visual judgment. The geometric features of the cracks extracted by each edge detection algorithm are further analyzed in the next section, and the applicability of each algorithm is compared quantitatively.

3.2 Quantitative analysis

This section provides a quantitative analysis of different edge detection algorithms based on crack length and area in pavement disease characteristics. First, the original image was opened in the image processing software and zoomed in and out to provide good visibility; after visually observation, the line was drawn along the crack by the point-by-point manner; then the real shape of the crack was determined and its length and the enclosed area were measured by the measuring tool. These were taken as base values for comparison and evaluation of each edge detection algorithm.

As described in the previous section, in this case study 100 pictures containing cracks were classified into 12 groups according to the types of cracks (horizontal cracks, longitudinal cracks, and alligator cracks etc.), the types of pavement (mixture) and the lighting conditions (bright and dark). For the detection algorithms that need initial threshold input, a sample of each group was randomly selected to obtain corresponding threshold for each group, respectively. For the Canny edge detection, the high threshold was taken as 2 to 3 times the low threshold; For the proposed combination algorithm, the OTSU algorithm was carried out and its segmentation threshold was taken as a high threshold, whereas 1/3 to 1/2 of this value as a low threshold. Results of multiple group experiments showed this can better retain the weak edge.

Different detection algorithms were used to identify the geometric features of the three types of cracks (horizontal cracks, longitudinal cracks, and alligator cracks) respectively. The results were summarized in Figure. 2 and Figure. 3. The ordinate in Figure. 2 indicated the recognition rate of crack types. The ordinate in Figure. 3 represents the average accuracy of the crack feature extraction.
From Figure 2, it can be seen:

- Recognition accuracy of crack types. From the observation of Figure 2, both the adaptive edge detection algorithm and the proposed combination algorithm performed well in the case of horizontal cracks, longitudinal cracks or alligator cracks. Whereas the LoG algorithm was not ideal for various types of cracks due to its sensitivity to noises.

- Crack geometry features extraction. For horizontal cracks, proposed combination edge detection algorithm showed the best performance; for longitudinal cracks, proposed combination edge detection algorithm was also the best; and for alligator cracks, the best effect can be obtained by the regional adaptive algorithm.
4. Conclusions
A new Pavement Defect Detection system Utilizing UAV was developed to avoid blocking the traffic flow and to enlarge the coverage of the road surface area. Special module for flight control was programmed to achieve automatic taking-off, attitude change and trajectory control. Experiment results indicated that this module can meet the requirement of Pavement Defect Detection.

The contrast result showed that the proposed combination edge detection algorithm performs the best for both transverse cracks and longitudinal cracks, whereas the regional adaptive algorithm have the best identification effect for alligator cracks.

Experiments also showed that taking 1/3 to 1/2 of the value obtained by OTSU as a low threshold of Canny algorithm can retain the weak edges in the image and increase the detection accuracy.

In this case study, only the image-based methods were integrated and tested for pavement defect detection. Other methods such as laser and ultrasound may also has some advantages in crack identification. Moreover, for the proposed method, the optimization of identification algorithm should be further studied so as to improve both the recognition rate and efficiency.

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