A High-Speed Image Processor for Detection of Pavement Cracks

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Abstract

A system to detect and evaluate the crack on the pavement of the road was developed. A movie film is used as an input source. The system consists of a special film scanner, high-speed image processor, and the workstation. This paper presents an overview of the image processor and the algorithms to detect cracks effectively on real-time hardware.

1. Introduction

Examining the damage of the pavement is important for the maintenance of the road. Organizations that are in charge of the road pay much attention to the evaluation of the damage. There are several types of pavement damage, and cracks are one of the most important one among them.

Currently, specialists evaluate cracks by eyes from the photograph of the road printed on the movie film with a slit camera on a special car. Our system helps the evaluation using image processing. The film is scanned, and cracks are segmented with a high-speed image processor and the result is sent to a workstation, where the level of the damage is evaluated by software.

2. Algorithms of Crack Detection

2.1 Digitizing Film Image

The image of the road is printed on the 35mm movie film with the scale of 1/200. The film should be read with the high resolution; some narrow cracks that should be found are 1-2mm in width. Also, the difference of optical density between cracks and the road is around 0.5. Abe Sekkei developed a special film scanner for this purpose. It digitizes the movie film up to the 1000ft in length with 10 microns of resolution and 8-bit gray levels. A CCD linear array is used as a detector. The scanning rate is 8Mpixels/s.

2.2 Image Processor

The size of raw image data from the scanner is too large to deal with on a workstation. For example, in case of 1000 ft. film, the data is about 100GB in size.

Thus, a pipe-lined image processor that works synchronously with the scanner is developed to binarize the image and reduce the number of pixels so that the total amount of data may be 1/200 of original one. In the new reduced image, cracks are represented by 1 and other area by 0. It is transferred to a workstation at the rate of 40kB/s, where cracks are evaluated with the software.

In the following sections, the algorithm for the detection of cracks is presented.

2.2.1 Tone conversion

Through experiments, we found that digital image processing should be performed in the optical density scale in order to segment cracks effectively. The density of the film differs much depending on the exposure and development condition. Fig. 1 shows examples of profiles of a light and a dark road image films. The difference between the average density of these two films is more than 0.7 that shows the light intensity through the lighter film is about 5 times as high as that through the darker film. Cracks are, however, recorded as the difference of 0.6 in optical density not depending on the average density. Thus, cracks are easily segmented by a differential operation on the density scale.

Fig. 2 shows the original image of the scanner. Since the response of CCD is linear to the light intensity, the data from A/D converter attached to the CCD should be converted into logarithmic scale using LUT. Considering the dynamic range of the CCD, we designed the output of this conversion as 8-bit data representing the optical density up to 2.2. Fig. 3 shows the same image in the density scale.

2.2.2 Smoothing

Road images contain high-frequency noise that interferes the segmentation of cracks. To reduce this noise, a Gaussian filter is applied to the image.

For the implementation, the filter size is 7x7. A simulation with software proved that larger filter such as 15x15-pixel filter is more effective for the noise reduction. We chose 7x7 because the hardware to apply such a large filter will become too complicated.

2.2.3 Crack Segmentation and Binarization

Several approaches are proposed to segment cracks. Three of them are described in this section.

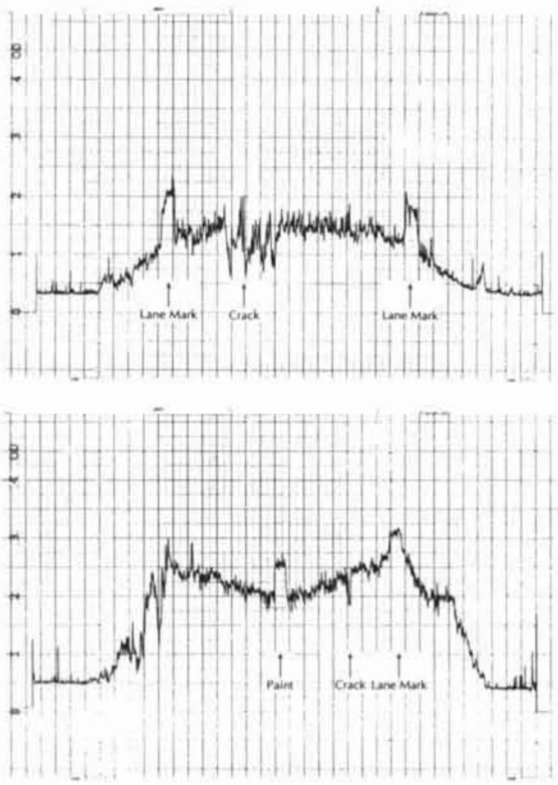

Fig.1 Profile of road image in optical density
Top: Light Film Bottom: Dark Film

First method is applying a band-pass filter to the road image and the segment cracks by binarizing the band-limited image. The advantage of this method is the robustness for the noise. There is also a disadvantage. In the experiments, we found that a large convolution filter such as 100x100 is necessary for the efficient segmentation. The problem is that implementing such a large convolvor with simple hardware is difficult.

The second approach is a dynamic thresholding. The road image is first divided into square blocks. The standard threshold of each block is determined by adding a fixed offset to the average pixel value of the block. To prevent the sudden change of the threshold, this standard threshold is interpolated using bi-linear interpolation [Asanuma89]. Though it requires the computation with large blocks, the operation is far simpler than the first method because we do not need a convolution. As disadvantage, the threshold is affected if the block contains extremely light or dark objects. For example, if there is a white line in the block, the threshold becomes lower and the binarized image becomes so noisy that the texture of the road is recognized as cracks.

The final method is detecting cracks as edges. There are two principle types of edge detector: one is the classical differential filter such as Sobel filter and Roberts Filter, and the other is zero-crossing method like Marr's or Canny's [Marr80][Canny86]. Generally, the latter is superior in the detection of smoother edges. For this application, however, a differential filter is adopted because zero-crossing methods detect the road texture that cannot be removed thoroughly by smoothing equally as cracks. We adopted Sobel

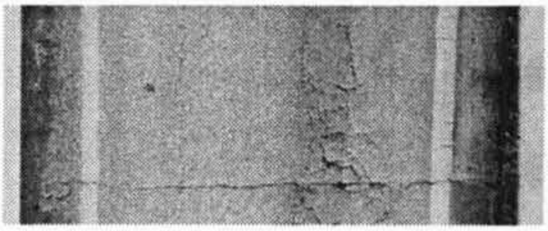

Fig.2 Original Road Image

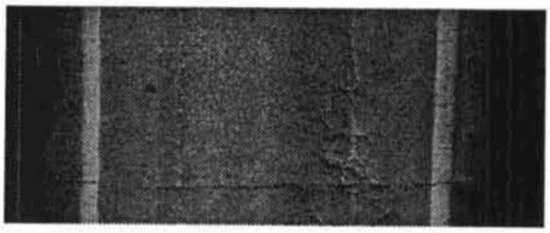

Fig.3 Road Image after Tone Correction

filter that showed the highest performance in edge detection and anti-noise robustness. The output of the Sobel filter is binarized with a fixed threshold. Fig. 4 shows the binarized image .

According to our experiments, the resolution can be reduced before the evaluation of cracks. The experiments showed that the binary image may be compressed to 1/8 without serious evaluation defect. Considering the convenience of later processing, we reduce the resolution of the images to 1/5 in the actual implementation. The image is divided into 5x5-pixel blocks and then, if the number of 1s in the block exceeds a certain threshold t_c, the new compressed pixel is set to 1, otherwise it is set to 0. A compressed image is shown in Fig. 5. The size of image data becomes 1/200 of its original size by applying these binarization and the compression.

There is an idea that the compression and the thresholding should be performed simultaneously. To realize this idea, we should not threshold the output value of Sobel operator directly but we should accumulate all the value in the 5x5 pixel block and then, threshold the accumulated value with a certain thresholding. This method enables a subtle control

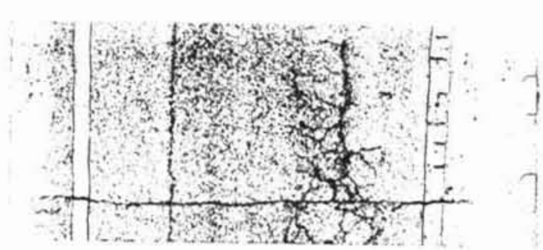
Fig.4 Binarized Edge Image

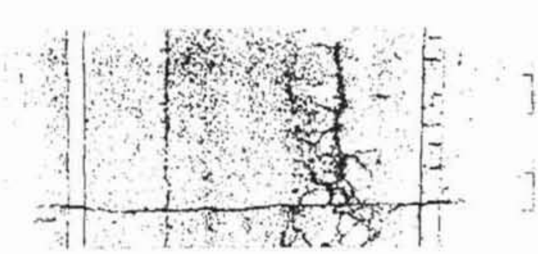
Fig.5 Compressed Image

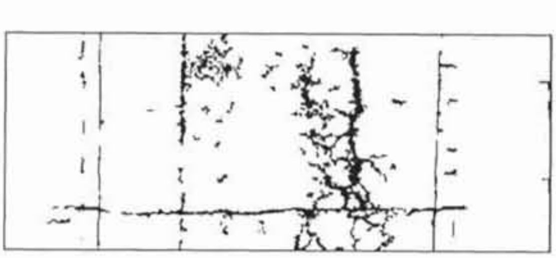
Fig.6 Final Crack Image

of the threshold. The problem is that the circuit becomes much larger because additional twenty-five 16-bit adders and one 16-bit comparator are required to realize this processing by the circuit. Thus we did not adopt this idea.

2.2.4 Processing of Binary Image

A compressed binary image still contains various noise and lack of necessary points. We have to perform binary image operation to get a better image. A point interpolation and removals of isolated islands are applied.

The point interpolation is realized by the following way. For each 0-valued pixel, we count the 1s in the 8-neighbor. Then, only when the counted number of 1s is more than the threshold t_i, the current point is changed to 1.

Next operation is removals of isolated islands. First, 3x3 or smaller islands of 1s are deleted. Then, 5x5 or smaller islands are erased. Most of the noise can be removed in this process, and we achieved the final crack image as shown in Fig. 6. The final crack image is sent to a workstation where cracks are evaluated.

3. Implementation

The block diagram of the image processor is shown in Fig. 7. First, image data from the scanner flows into a LUT where the intensity is converted to the optical density. Then, two-dimensional convolver applies a 7x7 Gaussian filter to the image for smoothing. Similarly, 3x3 Sobel operation is performed by a convolver for the edge detection. The image is binarized and compressed by 5x5 blocks. Finally, three binary operation is applied for the noise reduction and the compensation of missing pixels, and the image is sent to the workstation through an interface. There is also a frame memory with the resolution of 512x512 pixels for the maintenance such as adjustment of parameters.

4. Concluding Remarks

We develop a system for the evaluation of cracks on the pavement. A road image on the movie film is scanned and digitized by a special scanner. Since the image is huge, we also developed a high-speed image processor that segments cracks in the road image and reduce the image data to 1/200. This enables us to evaluate cracks efficiently.

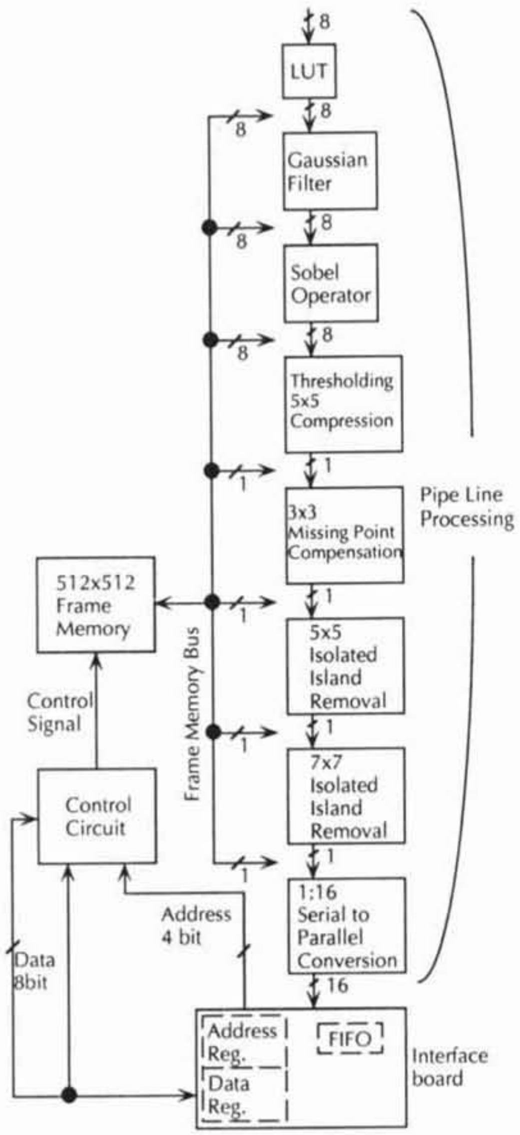

Fig. 7 Block Diagram of Image Processor

In future, we intend to develop a more advanced system that can perform real-time crack detection on board. That system will save much time and manpower that are currently necessary for the processing of films.

Acknowledgments

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