Using Kalman Filtering and Segmentation Techniques to Capture and Detect Cracks in Pavement

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Abstract: For this study we used a CCD video camera to capture the pavement image information via the computer. During investigation processing, the CCD video camera captured 10~30 images per second. If the vehicle velocity is too fast, the collected images will be duplicated and if the velocity is too slow there will be a gapped between images. Therefore, in order to control the efficiency of the image grabber we should add accessory tools such as the Differential Global Positioning System (DGPS) and odometer. Furthermore, Kalman Filtering can also solve these problems. After the CCD video camera captured the pavement images, we used the Least-Squares method to eliminate images of gradation which have non-uniform surfaces due to the illumination at night. The Fuzzy Entropy method calculates images of threshold segments and creates binary images. Finally, the Object Labeling algorithm finds objects that are cracks or noises from the binary image based on volume pixels of the object. We used these algorithms and tested them, also providing some discussion and suggestions.
Keywords: Kalman Filtering, Least-Squreas, Segmentation, Fuzzy Entropy

1. Introduction

Automatic pavement investigation has been researched [1][2] for several years. Due to the blooming of the mass transportation, nothing is more important than emphasizing importance of Aviation Safety. Therefore, maintenance for runway, taxiway and apron has become an essential part of aviation safety. Presently, the inspection methods of airport pavement are mostly by means of optic investigation, which is neither effective nor rapid. Moreover, less experienced, moody or fatigued investigators have sometimes led to erroneous or bungled estimates of pavement distress. Furthermore, the frequency of flights, such as ones at the Sung-Shan airport in Taipei city, with take-offs and/or landings approximately every five minutes, has caused difficulties for investigation during the daytime. Since the investigation must shift to the nighttime while the airport is closed, the investigation conclusions of the images were still non-uniform because of uneven gradation of synthetic illuminant.

In this study the pavement investigation system combined with the DGPS receiver and the CCD video camera synthetically collect data such as the DGPS location and the pavement images. After investigating the pavement, we got pavement images to analyze the crack parts of the pavement images with algorithms. In parts of the DGPS, we used the Leica GS5+ DGPS receiver. It can provide accuracy less than 1 meter of the position and combined with an odometer via the Kalman Filtering algorithm to control the CCD video camera capturing epochs and its absolute position, which is the way to avoid the image overlay at the same area. When the video camera collects images, it should pre-process before segmented to the binary images because of uneven gradation of synthetic illuminant during the nighttime. If images are not pre-processing from the beginning, the segmentation result will not successfully separate images of cracks or background. We used least-squares algorithm to approach the reflection trend for returning to the homogenous reflection of images. Finally, the Fuzzy Entropy is used to separate cracks and background for the pavement management system to analyze the type of cracks.

In this example, the Sung-Shan airport was the study area to capture and detect cracks in pavement. The least-squares method was used to eliminate the uneven gradation images and the Fuzzy Entropy to segment images to get bi-level images. Furthermore, to prove the above mentioned methods and algorithms could eliminate the non-uniform reflection and effectively separate crack and background, we used several types of images. It is essential to maintenance technical, analyze and discussion issues of crack in pavement in the near future.

2. Methodologies

1) Kalman Filtering

This algorithm usually applied to a dynamic system such as a moving vehicle. The location and velocity are the unknown parameters of the state vector. The vector is time dependent can be predicted from the system equation [3]. The predicted values can be improved or updated by observations containing information on the state vector. It corresponds to the sequential adjustment in the static case. We used the algorithm applied to integrate the DGPS receiver and the odometer signal output. The computer controlling the CCD video camera to capture images needs the odometer trigger signal. Unfortunately, the DGPS receiver can not immediately output the image's information (coordination, velocity, and accuracy etc.) because it outputs position messages every second and the odometer always triggers signal less than a second. Therefore, the Kalman Filtering can synchronize in the timing system. The advantage of the algorithm is that the system calculates the location just only reserves previous observation and adjustment data. It does not necessary to store a lot of history data for the prediction and update epochs.

The Kalman Filtering has three major steps: prediction, update, and smoothing. The prediction is to estimate the position where the CCD video camera captures image via the nearest observation and the previous calculation of optimal data. The update step is to re-calculate the optimal data that integrate the prediction location with the observation data. The finally smoothing step is to improve previous estimates for the captured image position, but it needs to be post-process when the investigation is completed. Fig.1 is the system procedure of the diagram.

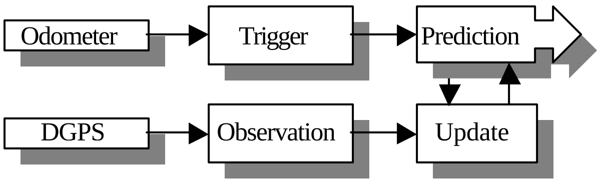

Fig. 1. The system of the Kalman Filtering

2) Homogenization Observation

The CCD video camera captured the pavement image at night. The illumination was not fully radiation to an entire image that the image reflected non-uniformly. They could not directly process segmentation progress. Therefore, the image had to acquire the feature of the reflected surface first, then adjust and homogenize the image to uniform reflected surfaces. Here is the definition of reflection function [4] in Eq. (1):

$$z = a_0 + a_1 x + a_2 y + a_3 xy \qquad (1)$$

Where x, y are the row and column of an image pixel, then z is a gray value of the pixel, and a_0、a_1、a_2、a_3 are the function of unknown parameters. Next we put the Eq. (1) into the observation function in Eq. (2), then used the Least-Squares method in Eq. (3) to solve the unknown parameters of a_0、 a_1、 a_2、 a_3 ：

$$V = AX - L \qquad (2)$$

$$X = \left(A^T A\right)^{-1}\left(A^T L\right) \qquad (3)$$

Here the L is the gray value z, A is the function (1) of the coefficient matrix. After the function (1) had been solved, then we can adjust and homogenize the reflected image.

3) Segmentation

Segmentation is a conversion from a gray value image to a bi-level (crack and background) image. It will reduce the complicated information of the image to the bi-level image contain the essential information such as objects, volume of crack pixels, and shape. Still, it is not easy to decide the threshold by human's trial and error. This method is also not suitable for every pavement image. Therefore, here we used the Fuzzy Entropy [5] method to solve the minimum entropy of the gray level image. When the minimum entropy value has been solved, that is the suitable threshold of gray value to separate the image.

The first step is to determine the fuzzy set of membership function in Eq. (4):

$$u_x(x) = \begin{cases} \dfrac{1}{1+\left|x-m_0\right|/C} & if \quad x \le t \\ \dfrac{1}{1+\left|x-m_1\right|/C} & if \quad x > t \end{cases} \qquad (4)$$

For a given C is a constant, x denotes all gray value, t is the threshold for segmentation, m_o and m_1 denotes the average gray value of crack and background in Eq. (5):

$$m_0(t) = \frac{\sum_{g=0}^{t} g \cdot h(g)}{\sum_{g=0}^{t} h(g)} \qquad m_1(t) = \frac{\sum_{g=t+1}^{254} g \cdot h(g)}{\sum_{g=t+1}^{254} h(g)} \qquad (5)$$

Here h is gray level histogram. We assume the image represents just two classes: crack and background, This can be calculated using the expression [6] in Eq. (6):

$$D_P(t) = \left[\sum_g \left|m_x(g) - m_{\bar{x}}(g)\right|^P\right]^{1/P} \qquad (6)$$

For all gray levels g, the value of P used defines a distance measure and $m_{\bar{x}}(g) = 1 - m_x(g)$. Then we get the Eq. (6) into the Eq. (7) to get the entropy:

$$E(t) = \frac{1}{MN}\sum_g D_p(t) \qquad (7)$$

Here N and M are the of rows and columns of the image. As result, the minimum entropy of the threshold value is for segmentation image.

3. Results

We captured images from the Shun-Shan airport in Taipei city. The visual results of all pavement images can be examined in Fig.2, 3, and 4. The sample images are as follow: Transverse, Longitudinal, and Diagonal cracks of sample images. In Fig.2(a), Fig.3(a), and Fig.4(a) are the original pavement images. We processed image via Homogeneity of result in Fig.2(b), Fig.3(b), and Fig.4(b) and the Fuzzy Entropy of results in Fig.2(c), Fig.3(c), and Fig.4(c) of bi-level images where white color is crack and black color is background. The results show that the algorithm can actually separate the crack and background images.

5. Conclusions

Kalman Filtering can provide the vehicle reliable positioning for the vehicle, combining the DGPS receiver and the odometer information. The theory only collects only one previous position information, such as coordinate, HDOP, and state function. The advantage is that the algorithm saves much calculation time and does not require collection more previous information. The odometer triggers the computer to capture images eliminating the problem of neighboring images being duplicated or gapped.

The Fuzzy Entropy algorithm in image processing can be used on segmentation of crack images. This avoids using trial and error methods to define each image of threshold value. For the future, we will continue to study how to eliminate the bi-level image of noise and classify the kind of crack types.

References

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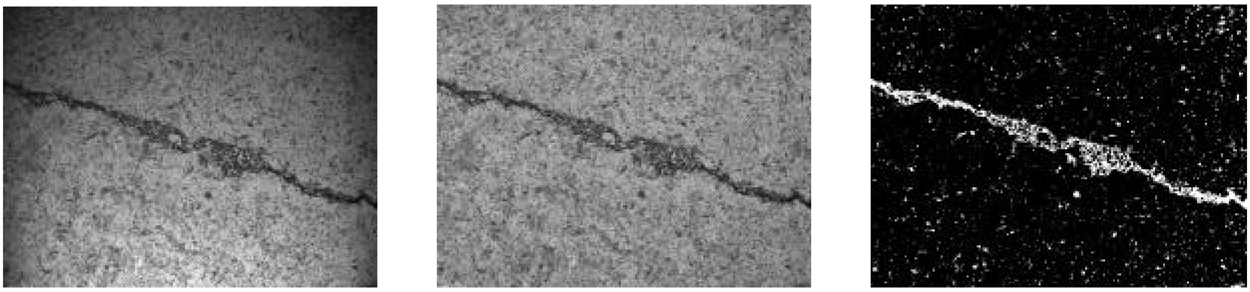
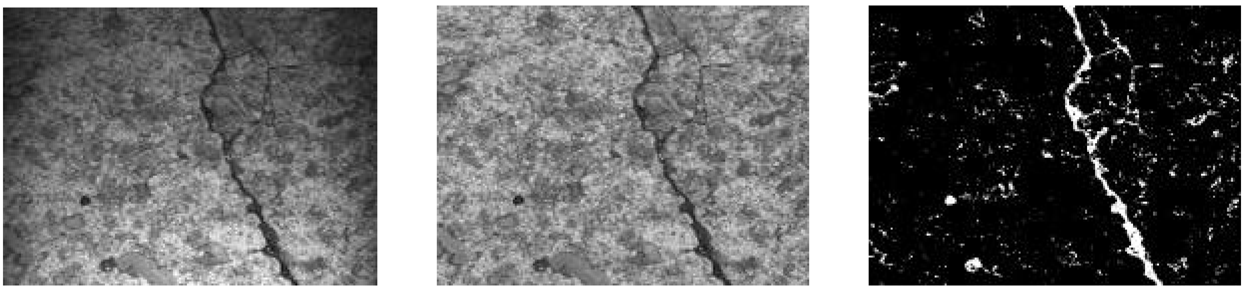


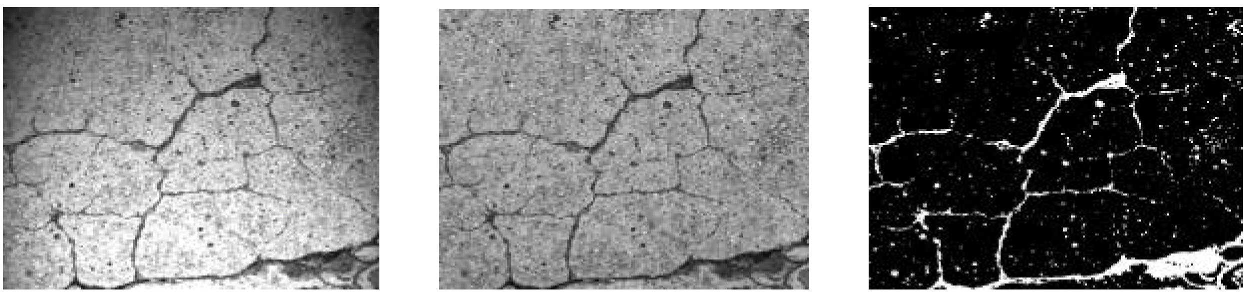
(a) (b) (c)

Fig. 2. Transverse crack image for test: (a) original image; (b) homogenous image; (c) bi-level image



(a) (b) (c)

Fig. 3. Longitudinal crack image for test: (a) original image; (b) homogenous image; (c) bi-level image



(a) (b) (c)

Fig. 4. Diagonal crack image for test: (a) original image; (b) homogenous image; (c) bi-level image