AUTOMATION OF PAVEMENT SURFACE CRACK DETECTION USING THE CONTINUOUS WAVELET TRANSFORM

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ABSTRACT

This paper presents a new approach in automation for crack detection on pavement surface images. The method is based on the continuous wavelet transform. In the first step, a separable 2D continuous wavelet transform for several scales is performed. Complex coefficient maps are built. The angle and modulus information are used to keep significant coefficients. Then, wavelet coefficients maximal values are searched and their propagation through scales is analyzed. Finally, a post-processing gives a binary image which indicates the presence or not of cracks on the pavement surface image.

Index Terms— Wavelet transform, image segmentation, image shape analysis.

1. INTRODUCTION

The French road network ages. Furthermore, road traffic increase and costs of road maintenance rise. So it’s important to detect defaults before the repair costs are too high. Pavement distresses are essentially due to heavy vehicle traffic and weather conditions. Nowadays, in France, thousand kilometers of roads are investigated each year. Currently, distress survey is made essentially by visual inspection. For this, qualified technicians drive in a vehicle whose speed is about 5 or 10 kilometers per hour and use an on board dedicated acquisition device. It goes without saying that this method is far to be safe, not only for road monitoring staff but also for road users. Due to the unceasing traffic increase, the automation of pavement surface distress monitoring is more and more required. One of the most promising techniques is to use image processing applied to pavement surface images previously acquired on road by a dedicated monitoring vehicle [1].

Most of image processing approaches depend on texture. They are frequently based on thresholding or filtering and frequently It’s need to adapt the threshold or the filter support to the texture ([2] and [3]). Such approaches reduce the crack detection performances (thin cracks are not detected) when pavement surface texture raised up.

To our knowledge few publications are available in literature for emergent crack detection ([4], [5] and [6]) by using wavelet-based image processing method. In this paper, after the problem position and a brief presentation of pavement surface images, we expose a new approach for automation of crack detection using a 2D wavelet-based image processing method. Some results are shown and analyzed. Finally, conclusion and perspectives are given.

2. PROBLEM POSITION

Pavement crack detection is a difficult edge detection problem due to various pavement textures that can be encountered on pavement surface images. A way to reduce the texture effect is to use low spatial resolution images. But low resolution tends to erase thin crack signatures. So, they won’t be detected by image segmentation. Consequently, we have chosen to work with images whose spatial resolution is between 1 and 2 mm per pixel. If we look forward to the final on road operational system, such spatial resolution seems to be realistic, due to available technologies on the market.

Examples of pavement surface images are given on figure 1. Images (a) and (b) are laboratory images. A bituminous concrete, whose aggregate maximum size is 14 mm, is given in image (a). The surface dressing whose aggregate size are 6/10 mm and 2/4 mm is displayed in image (b). Figure 1 (c) represents an image of a circulated road acquired in static mode with an alligator cracking on its surface. Figure 1 (d) represents an image of a circulated road acquired in static mode with a crack in a star shape on its surface.

Figure 1 also illustrates problems that may be encountered during the crack detection process. A major problem is the road texture. Indeed, for strong textures (like this represented figure 1 (b)), some spaces between aggregates are wider than the crack itself, so in such conditions it’s hard to detect the default. A second important difficulty is
lighting conditions, the cast shadows problem is represented in figure 1(c) for example.

![Figure 1: example of laboratory images (a and b) and real road images (c and d)](image)

3. THE WAVELET-BASED IMAGE PROCESSING METHOD FOR CRACK DETECTION

In this paragraph, we describe the proposed wavelet-based method for pavement surface crack detection. Some illustrations of results obtained at different steps of this method are given.

3.1. The proposed method

A general scheme of the proposed method is given onto figure 2.

![Figure 2: scheme of the image processing method proposed for pavement crack detection](image)

This method can be separated in three steps from the original pavement image surface to be analyzed to the pavement crack map binary image generated.

The first step use the 2D continuous wavelet transform (CWT) [7] applied to pavement surface image. We only remind here the 2D CWT expression:

$$Wf(a, b, \theta) = \int_{\mathbb{R}^2} f(\vec{x})\psi^*_\theta(\frac{\vec{x} - \vec{b}}{a})d\vec{x}$$

Where:

The base atom $\psi$ is a zero average function, centered around zero and of a finite energy, $a$ the scale parameter and $b$ the translation parameter.

During this first step the 2D CWT is only performed for both the 0° and the 90° directions and at several scales. Furthermore, after testing on various pavement image surfaces ([4], [5]), the mother wavelet chosen is the Mexican hat function.

3.2 Complex coefficient maps creation

As we only explore two directions, a complex number was introduced in the process. The real part of this number is the result of the cwt on the direction 90° and the imaginary part is the result of cwt on the direction 0°. This step is schematized onto figure 3. From these complex coefficient maps, modulus and phases maps are built for the different scales computed.

![Figure 3: complex coefficient maps](image)

As an illustration, modulus (bottom left) and phase (bottom right) maps are given onto figure 4 for the pavement image surface shown on the upper part.

Assuming that, on the original image, the crack is darker than the texture, such complex maps approach is useful to reduce the next segmentation step.

Due to the mother wavelet chosen, coefficients corresponding to a crack must be negative for both directions. So, only modulus of coefficients whose
associated angle is between –90° and -180° will be considered in the maxima propagation seeking. Furthermore, a first threshold on low modulus value may also be applied here to eliminate low coefficient values that do not match pixels belonging to a crack.

![Figure 4: example of modulus and phase maps at scale 4](image)

### 3.3 Segmentation of the wavelet coefficient maps

This segmentation step follows the maximal wavelet coefficients through scales from the largest to the smallest one. For this, the wavelet coefficient maximal value is searched, on the modulus map at a given scale, using a 1D-structuring element whose size is the support length of the mother wavelet at this scale (9 pixels at the first scale). This search is done by sliding the structuring element with an analysis step of 1 pixel. This operation is repeated on each row and column of the modulus maps computed before. At the end, a set of maxima maps are obtained. Figure 5 shows the location map obtain on the modulus map presented onto figure 4.

![Figure 5: maxima location at scale 4](image)

As one will observed on figure 5, the map obtained is noisy due to the location procedure used that do not used at that stage the propagation information through scales. So, in the second stage of the segmentation step, the propagation through scales is examined to go up to defaults (cracks).

Figure 6 details the process of maxima research. A maximal value at scale \( p \) propagates if a maximal value is found in its neighborhood at scale \( p-1 \). Thus, maxima which remain at the smallest scale (scale 1 in figure 6) belong to a default.

![Figure 6: maxima propagation through scales](image)

An example of result is shown onto Figure 7.

![Figure 7: binary image after propagation through scales](image)

The new map (binary image) obtained at that stage is still influenced by pavement surface texture, which induces a fragmentation of the object size detected. So post-processing is needed to reconstruct the object (crack). It consists in linking small regions to obtain larger ones before applying threshold on region size. For this, a skeletonization is performed and the end of regions is sought. The research is done in a 5x5 structuring element around the considered end of the object and link the central pixel \((p_i,j)\) as follow:

\[
\begin{align*}
\text{if } p_{i-2,j-2} = 1 & \text{ or } p_{i-2,j+1} = 1 \\
\text{then, } p_{i-1,j-1} = 1 & \text{ or } p_{i-1,j+1} = 1 \\
\text{if } p_{i-2,j+1} = 1 & \text{ or } p_{i-2,j-2} = 1 \\
\text{then, } p_{i-1,j+1} = 1 & \text{ or } p_{i-1,j-1} = 1 \\
\text{if } p_{i+1,j-2} = 1 & \text{ or } p_{i+1,j+1} = 1 \\
\text{then, } p_{i+2,j-2} = 1 & \text{ or } p_{i+2,j+1} = 1 \\
\text{if } p_{i+2,j-2} = 1 & \text{ or } p_{i+2,j+1} = 1 \\
\text{then, } p_{i+3,j-1} = 1 & \\
\text{if } p_{i+2,j-2} = 1 & \text{ or } p_{i+2,j+1} = 1 \\
\text{then, } p_{i+3,j+1} = 1 \\
\end{align*}
\]

if \( p_{i-2,j} = 1 \) then \( p_{i-1,j} = 1 \), if \( p_{i-2,j+2} = 1 \) then \( p_{i,j+1} = 1 \), if \( p_{i+2,j} = 1 \) then \( p_{i+1,j} = 1 \), if \( p_{i,j-2} = 1 \) then \( p_{i,j-1} = 1 \).
After the regions have been chained, a threshold is applied on the region size. All regions whose pixel number is under the median value of all region sizes are put to zero.

Figure 8: Final binary image and original image

4. RESULTS

The process described in the previous paragraph has been applied to road images presented onto figure 1. Resulting images are given onto figure 9. The cracks are well detected with more or less noise according to the texture. Thus, on laboratory images (a) and (b) the crack is detected but there is some noise due to a strong texture.

Figure 9: results examples

5. CONCLUSIONS AND PERSPECTIVES

In this paper, a wavelet-based image processing method has been presented. A complex representation for the separable 2D continuous wavelet transform has been developed. The angle information allows considering only coefficients that belong to the crack. Then, segmentation through scales was investigated. Future works consist in using matched filtering to define a mother wavelet function adapted to the road texture in order to automate the method for a wide number of textures. This method will be tested on road images database and rate of false alarm will be computed.

6. REFERENCES


