Advanced Engineering Informatics 30 (2016) 481–499

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Full length article

# Wavelet-morphology based detection of incipient linear cracks in asphalt pavements from RGB camera imagery and classification using circular Radon transform

Yashon O. Ouma [a,*], Michael Hahn [b]

[a] Department of Civil and Structural Engineering, Moi University, Eldoret, Kenya
[b] Department of Geomatics, University of Applied Sciences Stuttgart, Schellingstr, 70174 Stuttgart, Germany

ARTICLE INFO

*Article history:*
Received 3 March 2016
Received in revised form 13 May 2016
Accepted 16 June 2016

*Keywords:*
Micro-linear asphalt pavement distresses
Partial area effect (PAE)
Discrete wavelet transform (DWT)
Successive morphologic transform filtering (SMF)
Circular Radon transform (CRT)
Dice similarity coefficient

ABSTRACT

The combined detection, extraction and identification of incipient or micro-linear distresses in asphalt pavements are important steps in the quantification and analyses of the occurrences of linear distresses for early pavement management and repair (M&R). This study presents an empirical approach for the formalized identification of incipient linear structural failures in asphalt pavements, which are characterized by longitudinal, transverse, diagonal, block (random) and alligator (fatigue) distresses. Because of the spectral and spatial complexities in detecting distress features at very high resolutions, this study presents a triple-transform approach for distress detection, isolation and classification that comprises of: (i) 2D discrete wavelet transform (DWT) for multidirectional and multiscale linear distress detection; (ii) successive morphologic transformation filtering (SMF) as an adaptive filter for the extraction of linear distress shape and continuity, and (iii) circular Radon Transform (CRT) for angular-geometric orientation analysis for the identification and classification of the distress types. Using mobile RGB camera imaging, 72 pavement distress images, at a spatial resolution of about 1 mm were selected for evaluating the proposed approach. The results of the DWT-SMF were validated using the Dice coefficient of similarity between the manually segmented distresses and the study results. The validation results show that the linear distresses are satisfactorily extracted with an average detection rate of 83.2%. The average processing time for implementing the DWT-SMF phase of the algorithm was approximately 125 s. To validate the classifications of the distress types, the CRT results were matched with the reference classifications from synthetic cracks, with all showing positively corresponding results. In overall, the results of the study illustrate that the proposed triple-transform approach provides a reliable approach for the detection, isolation and characterization of linear distresses in flexible asphalt pavements.


## 1. Introduction

Flexible asphalt pavements are continuously subjected to non-uniform traffic loading, stress, and variations in climatic and environmental conditions. This, over time results into structural and functional deformations which are manifested by pavement cracks. Cracks or distresses on pavement surfaces reduce the design-life and the economics of the road surface. Through early road condition surveys and analyses, asphalt pavements with incipient deteriorations can be identified and if maintenance and repair (M&R) is carried out in time, then the overall M&R costs will be reduced by up to 80% [13].

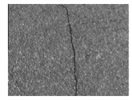
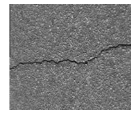
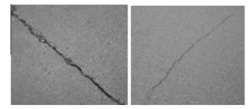
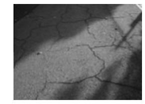
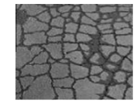
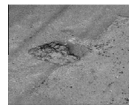
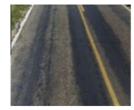
As summarized in Table 1, asphalt pavement failures can be characterized as linear based, area-depth based and surface disintegrations as a result of pavement strength failure. The focus in this study is on the detection and extraction of linear distresses, at early or incipient stages, and their characterizations using imagery acquired from mobile RGB camera imaging system. Multichannel RGB camera has the advantage of spectrally discriminating and imaging particle analysis, which enables the separation and characterization of the different particle types on a heterogeneous surface. In this study, incipient linear distresses are also referred to as micro-linear pavement distresses, and are defined as thin curvilinear distresses with widths of not more than 10 mm. As compared to micro-linear distresses, macro-linear distresses are much easier to detect and isolate on paved road surfaces because of their sizes.

Typically, asphalt pavement surfaces tend to be very heterogeneous due to the characteristics of the pavement surface materials

* Corresponding author.
*E-mail addresses:* yashon_o@hotmail.com (Y.O. Ouma), michael.hahn@hft-stuttgart.de (M. Hahn).

http://dx.doi.org/10.1016/j.aei.2016.06.003
1474-0346/

**Table 1**
Categorization of flexible asphalt pavement distress types (e.g. Li et al., 2012).

| Road distress category | Distress characterization and idealized distress type image | | | | |
|---|---|---|---|---|---|
| (a) Line-area road structural distresses |  (i) Longitudinal |  (ii) Transverse |  (iii) Diagonal (acute and obtuse) |  (iv) Block (random) |  (v) Alligator (fatigue) |
| (b) Area-depth based road pavement distresses |  (i) Potholes |  (ii) Patching |  (iii) Excess asphalt | | |
| (c) Disintegration due to pavement strength failures |  (i) Raveling |  (ii) Rutting | | | |

and aggregates; imaging and illumination constraints; background noise and environmental factors at the time of imaging. Thus spectral based imaging systems require a large amount of feasibility data to ensure the visibility of thin linear distress, which is identified by the intensity of the crack lines or the grayscale of the distress pixels [2]. This is because the intensity of the distress pixels, as illustrated in the next sub-section, may not appreciably differ from the neighboring non-distress pixels and also from the image background noise. For road condition mapping, video-based imaging techniques such as multispectral imaging systems and or mobile laser scanning are rapidly gaining popularity [41,34,13].

A lot of research has been reported on the development of pavement distress detection and recognition algorithms. Specifically, thresholding and edge detection based algorithms have been widely used for the detection and extraction of pavement distresses from camera based pavement images. These techniques however only perform the analysis at a single spatial scale. As a result, they are sensitive to background noise, since pavement images have various details at different scales [47]. Although advanced algorithms have been adopted in pavement-crack detection, limited success has been realized due to poor contrast resulting from, for example: reduced image amplitude range, noise from shadow, and lane markings [33,39,53,49].

Because of the inherent complexities in the detection of micro-linear distresses, the task may be ubiquitous but difficult task. The implication is that micro-linear distress features are likely to suffer from partial area effect (PAE). PAE is characterized by the loss of connectivity and orientation of the crack pixels, especially if the resolution of the imaging system in relation to the object size and noise elements is limited. As a consequence, partial area effect may result in the poor detection of crack sub-pixels in blurred and noisy images with low contrasts.

Multiscale image analysis and its robustness to noise make it an attractive tool for micro-linear distress detection in pavement images. The most common multiscale based approaches for pavement distress detections are wavelet transform [44,43,26,4,3], contourlet transform [27,54] and beamlet transform [51,50]. Most of these studies propose the use of more sophisticated classification ensembles, such as neural networks [30,32], and support vector machines [23] to deal with the road crack isolation or extraction problem. The main drawback of these classifiers is the supervised learning nature which requires a considerable amount of noiseless distress samples, for the proper representation of the pavement distresses.

This study presents a methodology for the detection of linear structural distresses in asphalt pavements using a triple-transform processing approach that is based on discrete wavelet transform for the detection of the linear distresses, successive morphological transform as an adaptive post-distress detection filter and for the accurate extraction of the shape and continuity of the detected distresses, and the circular Radon transform is used in the characterization of the linear structural distress type. In order to detect micro-linear distresses on paved surfaces, discrete multiscale based transform that operates on the textural variations and line orientation is proposed in this study. The undecimated or continuous multiscale wavelet decomposition not only requires higher computational load, but also results into high redundancy in the computed wavelet coefficients, making the subsequent computational processing such as edge detection and classification inaccurate and expensive. While distress detection and extraction presents the existence of distresses, the categorization or classification of the distress type is necessary in the quantification and analysis of the frequency of occurrence of a given distress in pavement condition evaluation.

### *1.1. Partial area effect (PAE) in linear distress detection*

In linear distress extraction, shape analysis is important in distinguishing between the micro-linear and the arbitrary neighboring pixels. This is because the micro-linear distress pixels form shapes which are visually distinct like lines as depicted in Fig. 1(a). On the other hand, shapes or objects formed by spurious intensity variation or grayscale level discontinuities also result into arbitrary objects and patterns with the same reflectance as the distress lines, and with blurred or fuzzy edges as illustrated in Fig. 1(b) and (c) for real and synthetic images respectively. This phenomenon illustrates the influence of partial area effect in linear distress detection. In the absence of PAE, the desired output is presented in Fig. 1(d) for the distress image in Fig. 1(c).

According to Li et al. [22], the intensity of a pixel $P_{i,j}$, $I(p_{i,j})$ on a pavement image (Fig. 1(b)) is the resultant of illumination and surface reflectance, and comprises of the following information components:

(i) the pavement distress and non-distress irregularities normally characterized by either wet road surfaces (oil and water) or dark reflecting materials on the road surface, and tend to have high-frequency components on the edges.
(ii) non-uniform background illumination, which is usually a very low-frequency signal, and