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DETECTION OF CRACKS IN ASPHALT PAVEMENT DURING ROAD INSPECTION PROCESSES

Summary. Road inspection is one of key processes of a pavement management system, whose function is to examine and describe the road infrastructure condition. When thoroughly performed, it provides the information required to implement an adequate road infrastructure maintenance policy and plan ad hoc repairs or refurbishments. This article discusses a solution for automatic asphalt pavement cracking detection, based on image-processing technology. This solution makes it possible to identify different crack types, i.e., transverse, longitudinal, alligator-type and technological cracks. The detection process is based on the application of various methods, including statistical difference identification for pre-assumed image analysis directions, i.e., in and opposite to the test vehicle running direction. The purpose of the morphological and filtering operations applied was to reduce the image noise level. The solution proposed was verified using video material in the form of a sequence of images recorded using the test vehicle.

Keywords: microlinear asphalt pavement distresses; crack mapping; line detection; crack pavement

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1. INTRODUCTION

Every day around the world, there are road accidents. Traffic participant faults, transport breakdowns and poor road infrastructure contribute to their creation. It is most difficult to eliminate the first mentioned causes [1, 2]. Appropriate diagnostics of the means of transport (for example, by non-invasive methods [3, 4]) can reduce their cause in road accidents. The last element is road infrastructure, including the state of the roads.

Road pavement crack detection is one of elements of the road inspection process. It comprises problems of crack analysis [5, 6], crack classification [7], crack depth estimation [8, 9] and crack sealing [10]. The most popular solutions used as asphalt pavement crack detection tools are based on the analysis of dependent variables in the pixel intensity function. A threshold value established by the application of statistical measures of the image intensity function determines whether pixels should be assigned to a crack or to its vicinity [11].

In the studies described in [12, 13], the wavelet transform of an image was used to detect road pavement cracks. A comprehensive analysis of multi-resolution was proposed, where the determination of texture characteristic curves was based on the Haar, Daubechies, Coiflet, ridgelet and curvelet transformations. A critical assessment of multi-resolution analysis and statistical thresholding methods, as well as edge detection and wavelet transforms, is provided in [14].

Machine learning-based solutions for the detection of road pavement cracks are described in [15], which reports on a study in which the graph cut segmentation technique [16, 17] was applied to find crack and background regions in the image. For classification purposes of cracks, specific characteristics were defined to describe factors on which defects depended. The identified cracks were classified according to individual sets: transverse cracking, longitudinal cracking, block cracking or alligator-type cracking. The solution described in [18] is based on a similar concept, the only major difference being that images are recorded using vehicle windshield-mounted cameras. The sequence of images recorded shows the road infrastructure, vehicles, pedestrians and buildings. Using simple linear iterative clustering [19], the road pavement surface is extracted for further calculations, while dependent variables of the intensity and texture function are used to identify image descriptors. Analogically to the study described in [15], characteristic curves describing the dependences conditioning the occurrence of cracks were defined for the support vector machine. Problems of crack detection have also been addressed in [20, 21, 22].

2. ASPHALT PAVEMENT CRACK DETECTION METHOD

The method proposed in this paper for asphalt pavement crack detection is based on the analysis of differences between dependent variables in the function of intensity of successive pixels in an image line, with the mean dependent variable of the intensity function calculated in the given image area. It takes into consideration the dependent variable in the intensity function for the pixels, subject to analysis in the detection process, such that specific objects, i.e., defects of another type which do not belong to the pavement crack group, are cut off in the image. The determined threshold values make it possible to unambiguously assign pixels of the image to the existing asphalt pavement cracks. They are calculated for large image fragments, which increases the probability of the adequate estimation of the threshold value in statistical terms.

The proposed asphalt pavement crack detection method comprises the following consecutive actions:

- Road image acquisition
- Image noise filtering
- Image breakdown into fragments
- Determination of mean dependent variables of the intensity function for preset image fragments
- Determination of deviation values for a preset estimation window
- Determination of thresholding parameter levels
- Identification of pixels belonging to a crack group
- Image morphology operations
- Segmentation of image objects/crack identification
- Creating records of identified cracks

A sequence of asphalt pavement images recorded by means of a CCD camera is used in the detection process. The acquired image designated as *I* is 1,024 x 768 pixels in dimensions and features an 8 bit colour depth. The images are subject to low-pass filtering given by the following formula:

$$I(i,j)=\begin{cases}-1 & if \quad I(i,j)>p\\ I(i,j) & otherwise\end{cases} \tag{1}$$

where:

p – cut-off threshold level estimated depending on the illumination conditions during image acquisition

Once the filtering procedure is completed, images are divided into fragments (Fig. 1) and the mean dependent variable of the range intensity function is established. The proposed breakdown results from the necessity to eliminate the non-uniformity of illumination, as well as image distortions in the optoelectronic system which affect the analysis of pixels and crack detection.

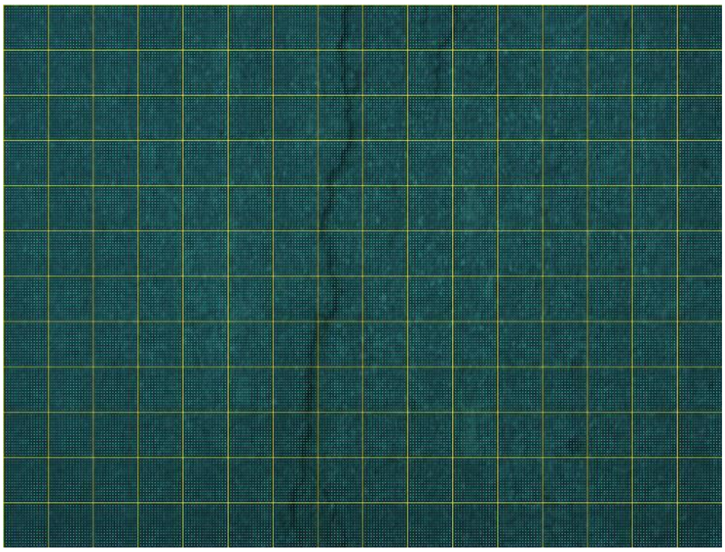


Fig. 1. Breakdown of a sample road image into fragments

The assumed breakdown of image *I* into fragments of 64 x 64 pixels in size constitutes a complete horizontal and vertical division of the image into 16 and 12 fragments, respectively. For the image fragments subject to analysis, the mean dependent variable of the intensity function is calculated according to the following formula:

$$F(m,n)=2^{-8}\sum_{(i,j)\in G} I(i,j) \tag{2}$$

where G is the set of coordinates *(i, j)* of image *I* used to determine the mean dependent variable of intensity function *F* with indices *(m, n)*, as given by the following formula:

$$G=\left\{(i,j):\begin{array}{l} i=m\cdot SFH, m\cdot SFH+s,\ldots,(m+1)\cdot SFH-s \\ j=n\cdot SFV, n\cdot SFV+s,\ldots,(n+1)\cdot SFV-s \end{array}\right\} \tag{3}$$

The next step in the detection method consists of determining the value of deviation *D* for the given estimation window *M*, which has been defined as the *n* set of successive pixels in the given line or column of image *I*. A graphical interpretation of estimation window *M* is provided in Fig. 2.

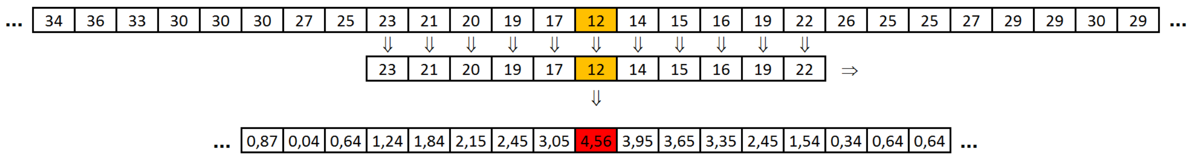


Fig. 2. Graphical interpretation of estimation window *M* for the value of deviation *D*

On account of the assumed crack detection methods, the procedure for determining the value of deviation *D* for the given estimation window *M* is performed twice, independently for all lines (4) and all columns (8) of image *I* under analysis, i.e., in the direction of the running test vehicle and in the opposite direction.

$$D^r(i,j)=\left(\frac{1}{|M^r|}\sum_{(i',j')\in M^r} I^2(i',j')-F^2(m,n)\right) \tag{4}$$

where M^r is the window for the estimation of deviation *D* in the dependent variables of the intensity function, given by a set of coordinates *(i', j')*, as per Formula (5); *m* is the horizontal index for the range of the mean dependent variable of intensity function *F*, given by the following formula: $m=i/SFH$; and *n* is the vertical index for the range of the mean dependent variable of intensity function *F*, given by the following formula: $n=j/SFV$.

$$M^r=\{(i',j'):\ \ i'=i-p^r\ldots i+p^r,\ \ \ j'=j\} \tag{5}$$

where p^r is the number of pixels analysed in a line to the left and to the right of the base pixel with coordinates *(i, j)* in image *I*.

The procedure for determining the values of deviation D^c for each preset estimation M^c for all columns of image I under analysis is conducted according to Formula (6):

$$D^c(i,j) = \left(\frac{1}{|M^c|} \sum_{(i',j')\in M^c} I^2(i',j') - F^2(m,n) \right) \tag{6}$$

where M^c is the window for the estimation of deviation D^c in the dependent variables of the intensity function, given by a set of coordinates *(i', j')*, as per Formula (7),

$$M^c = \{(i',j'):\quad i'=i,\quad j'=j-p^c \dots j+p^c\} \tag{7}$$

where p^c is the number of pixels analysed in a column above and below the base pixel with coordinates *(i, j)* in image *I*.

Fig. 3 presents an example of the identification of pixels belonging to a specific group of asphalt pavement cracks. It compares a graph of dependent variables in the intensity function for image I in the given column (the data of which are taken into consideration in the identification process), with a graph of deviations D^r determined for the pre-assumed estimation window of M^r. It additionally shows an image fraction with the analysed line marked.

In the interests of the automatic identification of cracks, for the initially determined values of deviations D^r and D^c of all pixels in image I, two criteria were defined to allow for the assignment of pixels depending on the analysis type: in lines (8) or in columns (9).

$$I^r(i,j) = \begin{cases} 1 & \text{if} \quad (D^r(i,j) > t_1^r) \cap (I(i,j) < 0.75 \cdot t_2^r) \\ 0 & \text{otherwise} \end{cases} \tag{8}$$

$$I^c(i,j) = \begin{cases} 1 & \text{if} \quad (D^r(i,j) > t_1^c) \cap (I(i,j) < 0.75 \cdot t_2^c) \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

where t_1^c, t_2^c are the threshold values of column c analysed in image I, chosen with reference to a linear regression model developed by the application of the least-squares method; and t_1^r, t_2^r are the threshold values of line r analysed in image I, chosen with reference to a linear regression model developed by the application of the least-squares method.

If one of the foregoing criteria points at the analysed pixel meets with coordinates *(i, j)* in image *I*, then it is a road pavement crack; otherwise, it is regarded as the background, i.e., the road image. In this way, a new road image of *I'* is created with the locations of cracks marked.

To enable the successful identification and recording of cracks in image *I',* one should perform a typical morphological operation, which consists of closing objects. This constitutes a combination of the operations of dilation and erosion, with the target object being 3 x 3 pixels in size [23]. What follows is an object segmentation procedure conducted with the application of the region growing method [24].

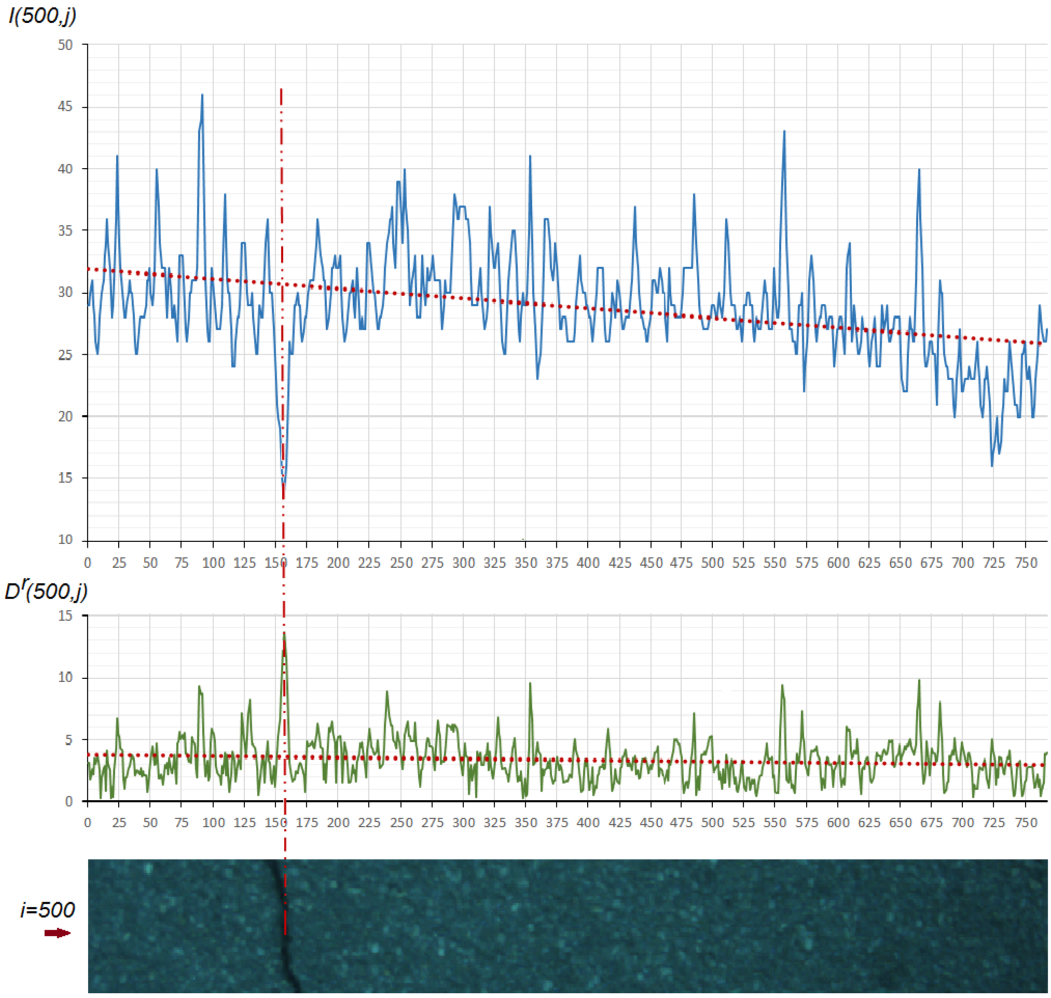
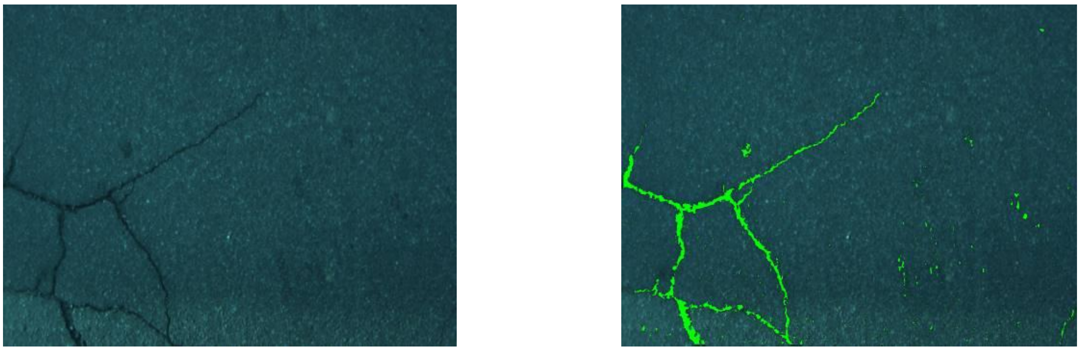


Fig. 3. Graphical representation of the crack pixels identification method

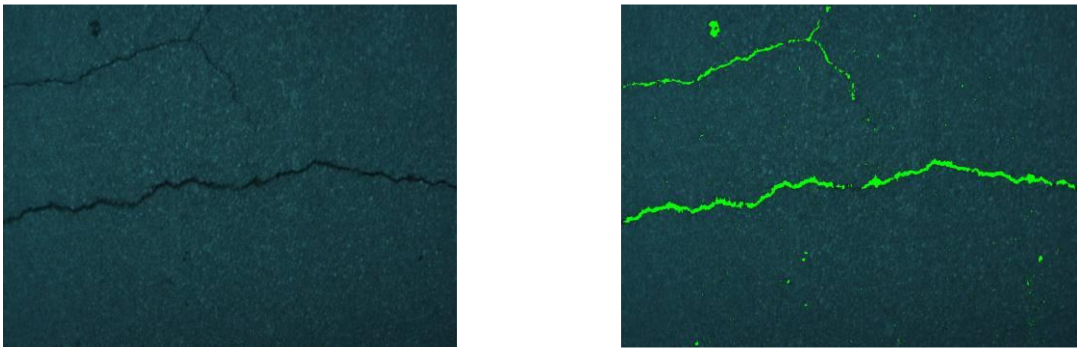
3. VERIFICATION OF THE PROPOSED SOLUTION

The asphalt pavement crack detection method was verified using test material, recorded as a sequence of images, which was taken by means of a stereo vision set installed on the test vehicle. The studies were performed on local roads whose overall test road section length came to about 1.6 km. Cracks were identified and recorded for 1,281 images in video sequences, which corresponded to about 0.983 km of the test road section. The cracks identified as a result of the measurements were of the longitudinal, transverse and alligator types. No technological cracks in the road pavement were found in the sections subject to tests. Fig. 3 shows selected cracks identified in the asphalt pavement being examined.

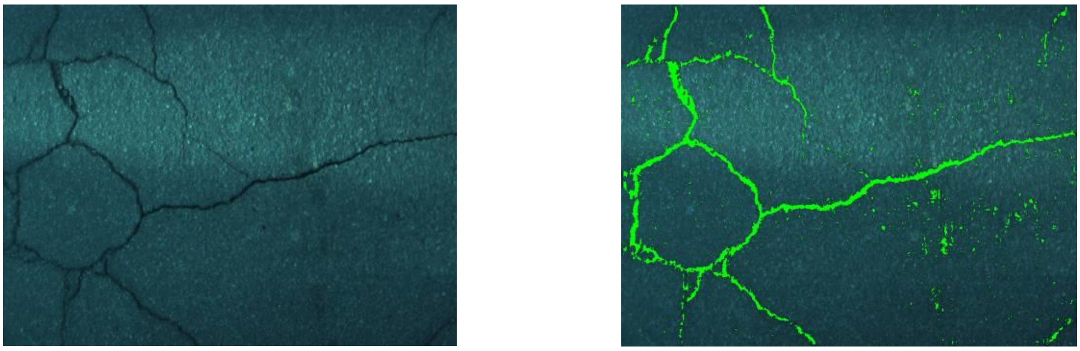
a) Longitudinal-type crack



b) Alligator-type crack



c)Transverse-type crack



d)Alligator-type crack

Fig. 4. Examples of identified asphalt pavement cracks

4. CONCLUSION

The paper provides a discussion concerning an automatic method of asphalt pavement crack detection, based on the application of image-processing technologies and the statistical analysis of the image intensity function. The studies addressed in the article provide grounds for an assumption that, once it has been implemented, the method in question enables crack detection at the level of 92% of all existing cracks identified by manual visual inspection (i.e., by an expert conducting road inspections). The solution assumed for this application makes it possible to identify longitudinal, transverse and alligator-type cracks. Meanwhile, owing to the segmentation operation, one can perform crack surface dimensioning and establish both the type and the scope of the necessary repairs.

The follow-up research endeavours involved in extending the detection method, as proposed in this paper, will cover the identification of cracks where chipping of the asphalt pavement grain can be observed. Further studies will also be undertaken to devise a method for the detection of patches and potholes, with the aim of developing a comprehensive tool for the identification of surface defects on asphalt road pavements.

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