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Self-correcting neural network in road pavement diagnostics

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ABSTRACT

The paper focuses on application of the self-correcting neural network in the process of road pavement diagnostics. It provides a discussion on a method of road inspection based on the proposed neural network solution and a measuring station which uses stereo vision of road pavement. The solution proposed was verified in real-life conditions, i.e. in a road with different types of pavement defects. With reference to a comparison of the results, a typical approach to estimation of disparity maps based on matching measures has been limited in favour of the solution in question. Both the results thus obtained and statistical analysis have confirmed legitimacy of the solution devised by the authors.

1. Introduction

Road pavement inspection is a key element of pavement management systems, and the results it brings provide grounds for the road pavement maintenance process to be performed with sufficient efficiency. The simplest inspection method is visual identification of defects conducted by qualified experts who simultaneously assess the extent and severity of the given defect. However, there are several flaws of such an approach, and these include high costs, subjectivity and non-repeatability of assessment as well as exposure to potential road traffic incidents during measurements. The above deficiencies entail the necessity to use different systems to complete the process of automatic identification and assessment of defects. When the said systems are in use, flaws such as the aforementioned ones are significantly limited or even eliminated, but they may become replaced by others which pertain to efficiency of identification, accuracy of description and assessment of defects as well as real-time performance of these processes. Automatic systems used for road inspection purposes are not encumbered with the problem of data acquisition during the measurement process, but they are sensitive to accuracy of data analysis which comprises distress detection and isolation, distress classification, pavement condition quantification, image compression and noise reduction, distress segmentation and maintenance [1]. The reason for the foregoing is usually poor contrast and a relatively high level of interference. By enhancing quality of the recorded images, one may contribute to qualitative and quantitative improvement of information which contains description of the road pavement defect.

Identification of road pavement cracks is a complex process performed on a real-time basis which comprises problems of crack detection and analysis [2,3], crack classification [4], crack depth estimation [5] as well as crack sealing [6,7]. Most algorithms applied for crack detection purposes are based on the value of the pixel intensity function, where the threshold value assigned to a crack or its surroundings is established by application of statistical measures of the image intensity function. A modified approach has been proposed by Huang et al. [3], and it involves breakdown of the road image into cells and assignment depending on the state of assignment of adjacent cells. Promising results can be observed while processing using the wavelet transform of image where multi-level texture analysis is applied [8,9]. The author of paper [1] proposed a comprehensive analysis of three forms of multi-resolution analysis used in the process of identification of cracks and pits. Characteristics of the textures were defined with reference to the Haar transform, the Daubechies transform, the Coiflet transform as well as ridgelet and curvelet transformations. Paper [10] illustrates an empirical approach to identification of linear defects of asphalt pavements showing signs of longitudinal, transverse, diagonal, random and alligator distresses. On account of the computational complexity in detection of the function of fracture description at high resolutions, a triple transformation approach was assumed in the study for purposes of distress detection, isolation and classification. The system comprises, firstly, the discreet wavelet transform (DWT) for multi-direction and multi-scale linear detection of defects, secondly, the soft morphological filtering (SMF) of transforms to function as an adaptation filter for linear extraction of shape and continuity of defects, and thirdly, the circular Radon transform (CRT) for the sake of analysis of angular and geometric orientation of defects as well as for their identification and classification according to individual types. However, Tsai et al. [11] performed critical evaluation of such crack detection

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methods as statistical thresholding, edge detection, multi-resolution analysis as well as wavelet transforms. A concept of a low-cost defect identification solution based on integration of multi-scale texture-based image filtering using wavelet transform has been discussed in [12]. In order to identify the defects, segmentation based on hybrid wavelet-FCM clustering is performed. It enables the edges of detected potholes to be smoothened and recognised. However, the prototype methodology was tested and validated using 75 experimental image datasets. For purposes of classification of road defects, authors of study [13] proposed an expert system based on the wavelet transform and the radon neural network. The task of classification is performed by means of a neural network using a feature extracted from wavelet decomposition and the radon transform. An extension to the expert system has been proposed in paper [14], where wavelet-radon transform and dynamic neural network threshold selection is used. The algorithm contains a combination of feature extraction using WR and classification using the neural network technique. An advantage of the systems thus developed is the neural network's capability of self-organisation during real-time work without the need for programming. Paper [15] addresses a method proposed to enable application of popular mobile devices for recognition of three typical road pavement defects, i.e. a bump, a longitudinal or transverse crack and a fatigue crack. The tool identifies the defects with factor 0.7 of Precision, Recall and F-Measure. However, it does not allow identification of patches, cracking curves or the shape of bumps. Under study [16], the Deep Convolutional Neural Network was used to detect cracks in Hot-Mix Asphalt (HMA) and Portland Cement Concrete (PCC) pavements. The network is trained by means of a set of road pavement images, including ones showing various defects, yet without fracture-type defects. Using the re-trained deep learning model enables practical application of the solution proposed. Paper [17] presents an innovative solution for detection of road pavement fractures using a quadcopter type unmanned aircraft. It features a multi-level image analysis system covering image processing as well as data thresholding and classification. Images are first converted, then, an adaptation threshold is applied to create a converted fracture template, and finally, the polar support vector machine is used for interpretation of crack distresses. The quadcopter-based system is potentially most useful in locations of obstructed visibility, as it causes no disturbance to traffic while performing road inspections.

A machine learning based approach to crack identification was proposed by Moussa and Hussain [18]. They used the Graph Cut segmentation technique [18,19] to find/segment “crack” and “background” regions in the image. They also defined seven characteristics describing the factors which condition the occurrence of cracks, and did that for classification purposes using the Support Vector Machine SVM. An identified crack can be classified under one of the following groups: transverse cracking, longitudinal cracking, block cracking or alligator-type cracking. Application of machine learning for identification of road pavement cracks, where images are collected from a camera mounted on the vehicle windshield, has been discussed in paper [20]. The foregoing means that input images comprise the road infrastructure, vehicles, pedestrians and buildings. In the first step, by application of the superpixel algorithm, i.e. simple linear iterative clustering [1,20], the road pavement surface is extracted for further calculations. Next, based on colour and texture, descriptors of object properties are computed. Analogically to the study described in paper [18], nine characteristic curves describing the relationships conditioning the occurrence of cracks have been defined for the SVM. Computer vision and machine learning techniques have recently been successfully applied to automate road surface surveying [21–25].

The subject of neural networks being used for identification of road cracks has been discussed in paper [26]. It is a complex system based on application of three neural networks: the image-based neural network, the histogram-based neural network and the proximity-based neural network. A critical component of the process in question is the image-based neural network operating with the accuracy estimated at 70.2%, however, it should be stressed that the accuracy of the this solution depends on the road pavement crack being identified. The method used for crack identification under the study described in paper [27] was the back propagation neural network with three layers. Its input layer is based on the features from the pre-processing of sub-images to train the BP neural network. The relationships characterising the hidden layer were defined experimentally with reference to the paper authors' experience. The crack occurrence probability is established on the output layer. However, in order to achieve high accuracy of road crack identification, one must first remove isolated spots (sub-images) and connect adjacent points, those which are identified as a crack. The statistical image description defined as a mean and standard deviation of the intensity function is used to train the neural network to select the thresholds [28]. However, this solution required application of a curve detector to eliminate isolated spots. The very final stage of the detection process is the Hough transformation whose direct outcome is identification and classification of cracks. Another solution has been described in paper [29], where the input for the identified neural network is the road pavement image divided into sub-images as wide as a typical road fracture. What one uses as the network input is a result of a comparison between binary matrices with the sub-image and median as well as maximum values of vectors summed column- and row-wise. The result received at the network output, on the other hand, is a crack type representing one of the following categories: transverse cracks, longitudinal cracks and alligator cracks. For the sake of better noise suppression, especially in small regions, the binary matrix is convolved with two convolution masks. Paper [30] describes a solution based on a convolutional neural network CNN trained on square image patches with the given ground truth information for the classification of patches with and without cracks. This solution has been compared with SVM [31] and boosting methods [32]. Paper [33] presents results of application of the methodology of road pavement condition monitoring based on an artificial neural network to data obtained by means of an accelerometer. Both this solution as well as previous papers of the same authors implies that a neural network is capable of reconstructing road profiles and related defects in a manner which ensures a good level of matching and correlation accuracy. This solution is based on an assumption that real-life profiles are unavailable, while test data are obtained by performing on-site measurements.

Potholes represent the second type of road pavement defects which one can easily identify on the road surface. Their identification is typically based on one of the following two methods: 3D reconstruction-based method or 2D vision-based method. The 3D reconstruction-based method consists in spatial mapping of the road pavement using a pair of video cameras arranged in a stereo vision setup. In publication [34] and report [35], Wang proposed a concept of application of stereo vision for road inspection purposes in order to identify typical pavement defects by area-based matching methods. He used the measure of normalised cross-correlation for matching of extracted image pixels. However, the author also mentioned specific restrictions precluding full implementation of the system under real-life conditions. Salari et al. [36], on the other hand, applied the measure of average sum of squares of intensity differences between corresponding pixels in matching stereo images. What they also proposed, among other concepts, was a background filtering algorithm as well as morphological operations to be used in the post-processing phase to compensate for uneven illumination. In SVM, road pavement is subject to segmentation using a colour determined by reference to RGB components as well as texture obtained by applying the Gabor filter [37]. A considerable flaw of the aforementioned stereo vision solutions is the need for spatial mapping of the entire road pavement examined. The pixel matching procedure for stereo images is complicated, which stems from the necessity to apply complex algorithms insensitive to texture irregularity and pavement colour.

In 2D vision-based methods, one may come across algorithms that record light signals displayed as a pattern of lines or a grid on the road