Automatic analysis of road pavement surface imagery

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Automatic analysis of road pavement surface imagery

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ABSTRACT

This paper proposes an automatic analysis system capable of processing imagery acquired using a laser road imaging system, aiming to support the visual distress data analysis made by an inspector. The analysis consists of two main steps: crack regions detection and crack type classification. The first step processes images (of size 4015 x 3786 pixels), covering one entire lane, to identify those regions containing crack pixels. For this purpose, an image processing technique based on dynamic thresholding and region binary entropy computation is used. The classification step resorts to a connected components algorithm to indentify crack 'objects', which are then classified using a pattern recognition system developed for this purpose, according to a subset of the crack distress types identified in the Portuguese Distress Catalogue. Finally, images are labeled as containing longitudinal, transversal, miscellaneous or no cracks. The proposed automatic system is evaluated over an image database composed of real flexible pavement surface images acquired during a survey, using a set of well-know statistical pattern recognition metrics and exploiting the availability of ground truth data manually provided (human labeling) for the entire image database. Promising results are obtained in both

crack detection and classification.

1. INTRODUCTION

Road pavement condition is traditionally assessed through periodical surveys conducted by skilled technicians (inspectors) from highway/road national agencies, collecting data about pavement surface distresses, among others. This inspection methodology (human inspection – walking or windshield surveys) is laborious and can be dangerous, especially in highways. To enhance the personnel safety during road surveys, data collection at prevailing traffic speeds is required. Imaging devices like the one provided by INO (1) can acquire road surface imagery at speeds up to 100 km/h, ensuring personnel safety even in high speed roads like highways. However, the usage of high speed data collection devices can produce a very large amount of data, difficult to process in real-time even by the most efficient inspectors.
The recent advances in digital image processing can be exploited to create a development environment, able to automatically analyze the acquired imagery and infer about the presence of surface distresses and their types (cracks and other degradations). This would contribute to speed up the analysis process and also to reduce the subjectivity of human analysis, as two inspectors may produce different analysis results over similar distress situations.
Approaches followed by researchers aiming crack detection and their type classification, includes Neural networks, Markov random fields or edge detectors (2) (3) (4) (5), image segmentation techniques (6) (7) and boosting classifiers (8).
This paper proposes an automatic approach that includes a image processing technique based on dynamic thresholding and region binary entropy computation for crack detection, followed by the usage of a simple 2D pattern recognition system to label images as containing longitudinal, transversal, miscellaneous or no cracks, a subset of the crack distress types identified in the Portuguese Distress Catalogue (9). Section 2 presents the proposed system architecture as well the image acquisition procedures. Section 3 presents experimental results, comparing it to previous relevant research work by the authors and also available commercial solutions for crack image analysis are examined. Section 4 draws some conclusions and presents hints for future work.

2. SYSTEM ARCHITECTURE

Using the proposed approach, imagery is acquired by INO's Laser Road Imaging System (LRIS), composed of two high speed/high resolution linescan cameras (each one acquiring half road lane) in conjunction with high power lasers positioned at the top back-side of a special road pavement survey vehicle (1). Each half road lane image has dimensions of 2048 x 4096 pixels and they are joined so that only one image covering the entire lane width is processed. After this join operation, a full lane image has 4015 x 3786 pixels, due to an overlap during the acquisition process. Figure 1 shows two samples of lane images from the database, both revealing the presence of cracks, as well as the white markings of the road lane limits. Although LRIS is capable of acquisition speeds that surpass 100 km/h, the considered imagery database was acquired at a speed of 70 km/h.
Each image is processed at a region level, instead of pixel level, where regions of 75 x 75 pixels (empirically chosen, after exhaustive testing) are used, providing a good compromise between

accuracy and complexity, also ensuring faster processing times and posing less memory storage requirements. For images having the dimensions mentioned above the storage of a 53 x 50 matrix is required.

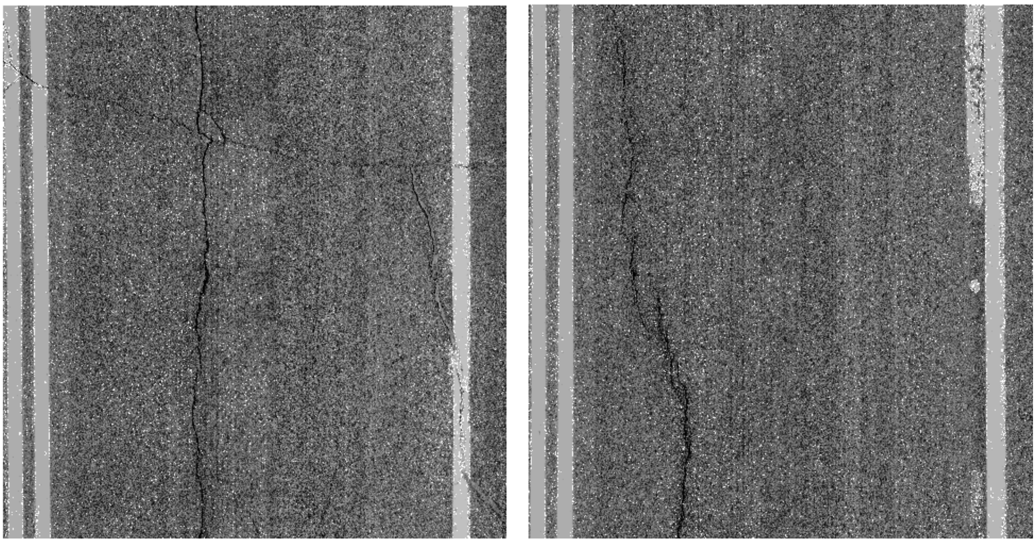

Figure 1: LRIS crack images with dimensions of 4015 x 3786 pixels, showing the entire lane.

Figure 2 shows the proposed system architecture. In the pre-processing stage, a morphological opening operation is applied to each image (10), to reduce the pixel intensity variance, arising from the image sensors used. This variance reduction provides more stable image intensity levels, notably in regions not containing crack pixels, while not affecting the ability to detect cracks, which are characterized by the presence of dark pixels.

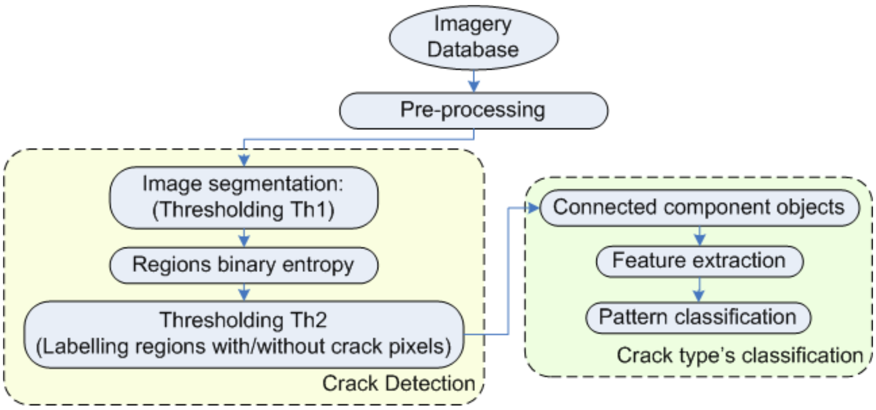

Figure 2: Automatic crack detection and type's classification system architecture.

The next step includes a first dynamic thresholding operation that segments the image, according to the expression:

$$Th_1 = Th_{ot} - 0.5 \times std(\mathrm{Img}) \tag{1}$$

where Th_{ot} is the image threshold value computed according to Otsu's method (10) and std(Img) is the standard deviation of image pixel intensities. The thresholding operation results in a binary image, where pixels with intensity lower than Th_1 are labeled '1', and '0' otherwise.

After this stage, the processing proceeds at a region level (75 x 75 pixels). The binary entropy (E_{br}) of each binary region is then computed according to the expression:

$$E_{br} = \left| f_0 \times \log_2(f_0) + f_1 \times \log_2(f_1) \right| \quad (2)$$

where f_0 and f_1 are the frequency of pixels labeled '0' and '1', respectively.
A region's binary entropy matrix, of 53 x 50 pixels, results for each image. A histogram is then computed from the previous matrix and another dynamic thresholding operation is applied, according to the expression:

$$Th_2 = 0.5 \times Th_{ot} \quad (3)$$

where Th_{ot} is again a threshold value computed using Otsu's method (10). This second dynamic thresholding allows labeling regions containing crack pixels, i.e. those regions with a binary entropy greater than Th_2, which are labeled '1' (crack regions). The remaining regions are labeled '0' and a new binary matrix is returned, with the crack region detection results.
To classify cracks according to their type, the binary matrices with the detection results are processed using a connected components algorithm. Isolated crack regions are discarded (relabeled '0'), as they are likely to correspond to noise, e.g., oil spots. For each resulting connect component, the standard deviations of its column and row coordinates are computed, forming a 2D feature space presented to a pattern recognition system used to label the images as containing longitudinal, transversal, miscellaneous or no cracks (11), a subset of the crack distress types identified in the Portuguese Distress Catalogue (9).

3. EXPERIMENTAL RESULTS

The automatic analysis system proposed here is evaluated using an imagery database composed by 75 full road lane width images, acquired at speed of 70 km/h, of which samples are shown in Figure 1. A manually provided ground truth is available, from human labeling, for the entire image test database.
A set of well-know metrics are computed to evaluate the system performance: precision (pr - rate between the number of crack regions correctly detected and the total amount of regions detected); recall (re - rate between the number of crack regions correctly detected and the number of crack regions in the ground truth); performance criterion (PC - an overall performance of the system, computed as combination of precision an recall metrics):

$$PC = (2 \times pr \times re) \div (pr + re) \quad (4)$$

Using the unsupervised automatic detection and classification system proposed in this paper, a precision value of 87.6% is obtained with the recall value reaching 93.3% and leading to a performance criterion of 90.4%. Notice that recall is the most important metric for this type of application, where not missing existing cracks is the main priority. These are considered good results, even if some false positives may arise.
In terms of crack type classification, recall and precision values of 100% are obtained.
A total processing time of 12 seconds per image is achieved, using a computer with a Pentium 4 processor at 2.66GHz and a Matlab algorithmic implementation. Part of the Matlab implementation has used the PRTOOLS toolbox for pattern recognition (12).
Also a graphical user interface has been developed for this project, a snapshot of a dialog box being shown in Figure 4.

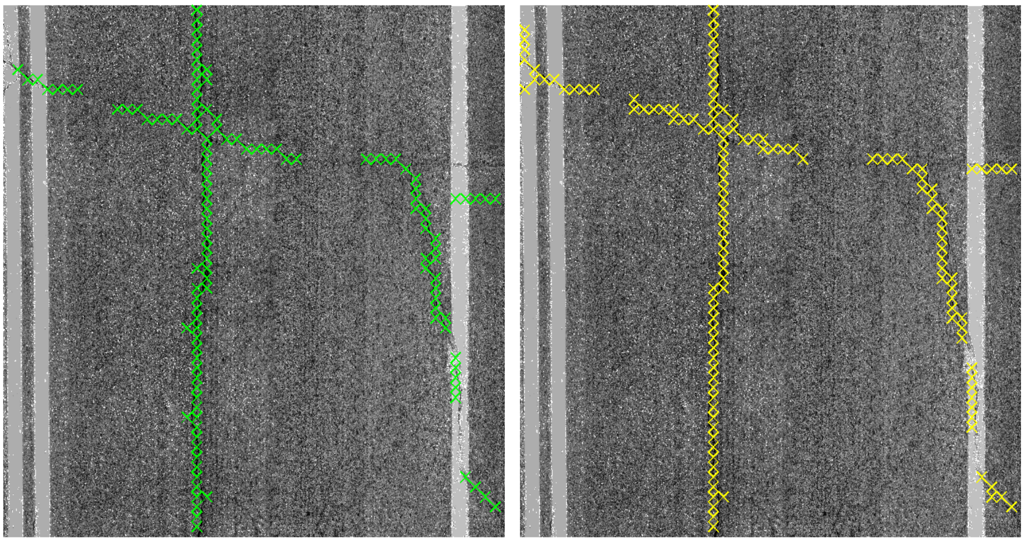

Figure 3: Experimental crack region detection result (left) and the respective ground truth data (right), for the left image show in Figure 1.

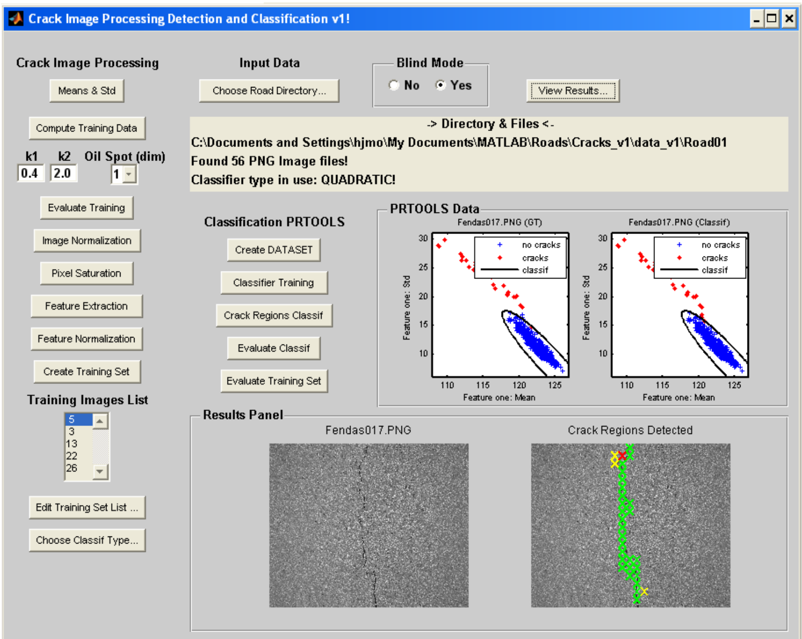

Figure 4: Graphical user interface of the automatic road surface imagery analysis software developed.

4. CONCLUSIONS AND FUTURE WORK

This paper purposes an approach for automatic analysis of road pavement surface imagery acquired by a high speed survey system. It is fully unsupervised and no training phase is required. This system aims at the detection of image regions containing crack pixels, and at the classification of the identified cracks according to a subset of the crack distress types identified in the Portuguese Distress Catalogue (9). Performance evaluation shows that a very good recall value is achieved at an affordable processing time, for in office processing.

Further developments of this research, at a semantic level, envisage a more complete crack distress type classification, as well as a severity level characterization. At the algorithmic level, a preprocessing stage capable of further reducing the variance of original images' pixel intensities, without affecting crack information. Also the use of more accurate dynamic thresholding procedures is targeted.

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