PATCH DISTRESS DETECTION IN ASPHALT PAVEMENT IMAGES

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ABSTRACT

Pavement condition assessment is an indispensable constituent in maintaining roadway infrastructure. Current practices for pavement condition assessment are labor intensive which introduce subjectivity in pavement rating and are time consuming. Automated methods rely on full 3D reconstruction of the pavement surface which introduces high equipment and computation costs. This paper presents a methodology for detection of patch type distresses in asphalt pavement images. This method uses filtering and histogram equalization for clearing and enhancing the image accordingly. It continues by applying the morphological process of closing, along with some rules based on the characteristics of a patch when captured in an image, to finally detect the area it occupies. Criteria for area, length, and width of a patch as seen in an image are taken into account to decide whether a probable patch is actually a patch. The method has been implemented in C#. The preliminary experiments demonstrate it produces promising recognition results

KEYWORDS

Pavement assessment, Patching detection, Image processing

INTRODUCTION

The road network of a whole country usually consists of thousands of miles of pavement. The materials used are bituminous, concrete or composite materials that range in condition, age and performance. Nowadays, several maintenance programs have been developed with the aim of monitoring and identifying distresses for assisting the rehabilitation and repair processes. Such a program is the Long-Term Pavement Performance program (LTTP) developed by the Department of Transportation of the United States, which is capable of collecting data, storing it and analysing it (FHWA, 2009). This program is greatly concerned with the process of pavement surface condition assessment and emphasizes the importance of reliable and good-quality measurements on pavement distresses such as cracks, potholes, rutting, patching etc. (FHWA, 2000).

Nowadays, the data collection is mainly automated and performed by accredited inspectors. The data is then post-processed in order to manually detect and assess defects. The current process not only requires great amounts of time and money, but it also introduces the factor of subjectivity and experience level (Bianchini et al., 2010). Costs could be greatly reduced if the pavement assessment method was automated. Computer vision and image processing techniques could be used not only for collecting data but also for processing it as well. Moreover, with automation the human intervention can be reduced to minimum and the results produced would be more precise and accurate. Hence, several research efforts have been undertaken towards the automation of pavement defect detection. This paper focuses on identifying patches on pavement images.

In this paper we present a novel method for identifying patches in images that include asphalt pavement surfaces. These images are collected from streets that include such a distress. Our approach is based on the main characteristic of a patch when that is shown in an image, which is its darker grey intensity than its surrounding. The method continues with the application of a median filter for reducing noise and then histogram equalization for enhancing the contrast. To continue, a morphological closing is performed for smoothing the contours included in the image. Finally the patch area is identified by following a set of rules, which were created after realizing the characteristics of a patch when that is shown in an image.

The method proposed has been implemented using the programming language of C#. Out of 48 images tested, which included 38 patches, 23 were successfully identified. Using the metrics of precision and recall, the preliminary results show that the proposed algorithm has an overall accuracy of 77% with 86% precision and 70% recall.

State of practice

The pavement assessment process is performed with the aim of identifying and examining the severity of pavement distresses. This process is divided into three stages: 1) collection of data, 2) identification of distresses and 3) assessment of defects. Currently, the first stage is mostly automated, whereas the other two are mainly manual.

For data collection, specialized vehicles equipped with video cameras for collecting pavement images/videos, optical sensors for measuring distance, laser scanners for capturing the longitudinal and transverse pavement profile, ultrasonic sensors for detecting rutting and accelerometers for measuring roughness are used. Such vehicles operate in traffic speeds and capture the condition of the pavement. Due to their high cost, many states have either a few or none available in their assets (MnDOT 2009; Fugro Roadware 2010). In cases where such vehicles aren't available, manual visual surveys are conducted (SDDOT 2009) from a vehicle that moves in very low speeds (8-15mph). It is obvious that no matter the equipment used, this stage leads to vast amounts of data.

The process continues with identifying the distresses and assessing the defects. During this stage, technicians are manually viewing and analyzing the collected video streams using computer work stations. Watching the videos using a number of screens, they identify where defects are present and then judge the defects' severity based on their experience and a distress manual (FHWA 2003; MnDOT 2003). Hence, the level of experience of the inspectors is very critical and it is inevitable for subjectivity to be introduced (Bianchini et al. 2010). Moreover, because of the great amounts of data, difficulties are faced on how to process them efficiently. Thus, only a sample of 10% is finally used for inspection and classification (Janish 2009).

The Florida Department of Transportation is using the Florida Automated Faulting Method along with an inertial profiler for automatically detecting joints and estimating faulting in concrete pavements (Nazef and Mraz 2010). However, this method is capable of only detecting transverse joints and estimating faulting on jointed concrete. The above limitations show the need of automation in the stage of the data analysis. Our research focuses on the defect of patches and on the automation of detecting patches in visual pavement data.

State of research

Research has mainly focused on algorithmic accuracy, leading to accurate but in most cases expensive and with implementation on dedicated vehicles, algorithms. In practice, the option of using dedicated vehicles in order to maintain a road network isn't feasible. It would be beneficial to move the monitoring task from the asset owners to the users that drive through the network in a daily basis. Under this idea, vision based methods can definitely assist the attempts of automating the pavement assessment (Tsai et al. 2010; Wang 2007).

Vision-based inspection can be separated into three stages. The first stage is the so-called presence. At that point, the inspection is a binary process under which a yes or no answer is provided on the set question, ex. whether a patch exists in an image. The second stage is the detection. During detection, the inspection is more detailed, specifying the region that a defect occupies the image. Finally, the most detailed inspection is the measurement, when the necessary information about the metric that can identify the defect is provided.

Several algorithms have been proposed for the detection of pavement cracks. Those algorithms are using different methods such as continuous wavelet transform (Subirats et al, 2006), a series of morphological operations (Maode et al, 2007), beamlet transform (Ying and Salari, 2010) and others (Hu and Zhao, 2010). Cracks are classified into 4 categories: transverse, longitudinal, alligator and block. Hence, methods for crack classification (thus, stage of measurement as far as inspection is concerned) have also been presented (Zhou et al. 2005; Sun et al, 2009). Moreover, studies have been performed for comparing proposed methods for crack classification (Rababaah, 2005) and crack assessment (Tsai et al., 2010).

Another pavement distress is potholes, which are the holes made at the pavement because of excessive stress or extreme weather conditions. An automated algorithm has been proposed for pothole detection in asphalt pavement images (Koch and Brilakis, 2011). The same team has also created an algorithm that identifies potholes in video data (Jog et al, 2013). Another proposed algorithm has the ability of detecting potholes in real time using android smartphones along with accelerometers (Mednis et al, 2011). The use of laser imaging has also been used for the same reason (Yu and Salari, 2011), providing additional analysis of the potholes' severity.

Elevation defects such as rutting, bumps and sags have also been studied. Rutting is the furrow made at the lane of the wheel. Sags are similar to rutting and are created by large weights or high pressure. 3D stereo vision and laser scanning systems have been used for this defect (Li et al., 2010). Although this method might be low-cost, it remains manual.

Attempts have also been made for the identification of patches. A method that detects patches amongst spalled cracks and punchouts has been presented (Yao et al, 2008). However, its detection probability is quite low. Another algorithm that identifies cracks, patches and potholes has also been proposed (Cafiso et al., 2006). This algorithm is able to distinguish between cracks and pothole/patch areas. Hence, it doesn't provide detailed information whether the distress is a patch or a pothole.

Problem statement, objective and delimitations

The current process of pavement assessment is time consuming and includes high costs. The main limitation is the vast amount of data collected and the necessity of its manual post-process from experienced technicians. Thus, the problem exists in the analysis of the data. Therefore, the overall objective of the work presented in this paper, is to propose a method that is able of detecting patches on pavement images.

The proposed method is based on the following delimitations:

1. In most cases, a patch has a greater grey intensity than its surroundings
2. In practice data collection is performed during the day and under natural light when the weather is either sunny or cloudy, but not rainy.
3. The images are taken from a height of about a meter, simulating the case that a camera is positioned on the rear of a car.
4. The entire patch is included in the image.

METHOD

In pavement surface images, color information isn't necessary. The reason is that in such an image the colors are mainly grey. Hence, in order to reduce the image complexity, initially a transformation into grey-scale is applied. The process continues with the application of a 5x5 median filter. A median filter is used for reducing the noise in an image. Noise is always introduced in images by hardware during the capturing phase. Noise is redundant and need to be eliminated. Thus the median filter is applied.

For enhancing the image, histogram equalization is applied. With this process, the contrast of the image is adjusted. It is necessary to do so for intensifying the grey-level detail. Then, the morphological process of closing and another method for filling holes in contours are applied. In this step the aim is to identify the different contours existing in the image. Finally the patch is detected based on the following rules:

1. A patch occupies 10% to 40% of the image. This is rule has been set based on the fact that an image will be taken from a height of about a meter.
2. The entire patch is included in the image.
3. Because of the above, the centroid of the patch is included in the image.

Figure 1 depicts the proposed patching identification method.

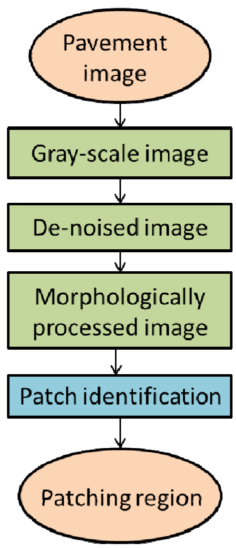

Figure 1 - Proposed patching identification method

Experimental design and implementation

The collection of data is performed with the use of a Canon VIXIA HF S100 camera. The performance is rated based on the indicators of precision and recall. Equation (1) shows precision, which measures the detection exactness and is the number of areas correctly detected (TP, True Positive) over the total number of areas correctly detected and incorrectly detected (TP+FP, True Positive + False Positive). High precision means that the detected areas correspond to actual patches in the images. Equation (2) shows recall, which measures the detection completeness and is the number of areas correctly detected (TP) over the total number of correctly detected areas and not detected at all (TP+FN, True Positive + False Negative). High recall means that most patch areas are correctly identified. Equation (3) shows accuracy, which represents the average correctness of the detection and is the number of areas correctly identified as patches (TP) and areas correctly identified as non-patches (TN, True Negative) over the total number of detected areas (TP + FP + TN + FN).

$$Precision = \frac{TP}{TP+FP} \tag{1}$$

$$Recall = \frac{TP}{TP+FN} \tag{2}$$

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} \tag{3}$$

Images were collected from the roads around the campus of Georgia Institute of Technology, Atlanta, Georgia. Those were processed by the algorithm which was written in C# using the Visual Studio .NET framework.

RESULTS

The proposed method was tested in 48 images. Those contained 1 to 4 patches, several discoloration spots intense shadows, a manhole or didn't have any defect at all. Table 1 presents the results of the metrics used to measure the performance of the algorithm. It is shown that our method has an accuracy of 80% with 76% precision and 70% recall.

The numbers indicate that the method is promising and is able to identify patches correctly in most cases. Figure 2 shows a selection of the results. In 2(a) we can see a patch correctly detected (True Positive). 2(b) shows an image at which only one of the included patched is detected (False Positive. 2(c) shows an image including a discoloration defect, which was correctly not detected as a patch (True Negative) and 2(d) shows an image of a patch which wasn't detected (False Negative).

Table 1 - Performance of the 48 pavement images tested

Performance	#
Total TP	19
Total FP	3
Total TN	18
Total FN	8
Accuracy	77%
Precision	86%
Recall	70%

(a) True Positive (b) False Positive (c) True Negative (d) False Negative

Figure 2 - Selection of processed images by the proposed algorithm

DISCUSSION

The preliminary results are promising but need further improvement. The overall accuracy is satisfactory, but both the recall need to be increased. First, a bigger dataset should be collected and tested in order to enhance the produced results and understand the current drawbacks. It seems, that the initial assumption that patches have greater grey intensity is true in most of the cases, but as seen in figure 2(d), this might not hold. So, this should also be considered and inserted into our algorithm. However, it should be pointed out that it is towards the method's advantage that it can successfully distinguish a patch from a discoloration spot, which can easily be misunderstood. Another factor that should be further studied is the case that an image includes more than one patch. Most of the False Positive results produced were due to that reason.

CONCLUSIONS

Pavement assessment is critical to the maintenance program of the road network. Currently the pavement assessment is as follows: 1) data is collected automatically via specialized expensive vehicles, 2) data is processed for distresses to be identified and 3) distresses are classified. This process is time-consuming, includes high costs and requires experienced inspectors. Thus, the research community has made attempts towards the automation of the pavement assessment procedure. Several methods have been proposed for the identification and classification of pavement distresses. However, only a couple are dealing with patches, but either produce poor detection results or can't distinguish the difference between a pothole and a patch.

This paper is focusing on the detection of patches on images including pavement surfaces. The main assumption of the proposed algorithm for identifying patches lies on the fact that patches have greater grey intensity than their surrounding when presented in a grey scale image. Filtering, histogram equalization and a method for filling holes is then applied for enhancing the contrast of the grey scale image and the contours included in it. Finally the patch is detected based on a set of rules.

Our method was implemented using C# under the .NET framework. 48 images containing pavement surfaces with a patch defect or not were tested. Out of 38 patches, 28 were successfully detected. The overall accuracy was 77% with 86% precision and 76% recall. The preliminary results are promising, however more images should be tested to enhance our conclusions and also identify the current limitations.

For future work, we aim at improving our algorithm and increasing the percentages of the performance indicators. The produced result showed us that we should consider the case that an image includes more than one patch. Also, we are interested into investigating the case that patches aren't darker than their surroundings.

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