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Visual analysis of asphalt pavement for detection and localization of potholes

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ABSTRACT

Identifying and restoring distresses in asphalt pavement have key significance in durability and long life of roads and highways. A vast number of accidents occurs on the roads and highways due to the pavement distresses. This paper aims to detect and localize one of the critical roadway distresses, the potholes, using computer vision. We have processed images of asphalt pavement for experimentation containing the pothole and non-pothole regions. We proposed a top-down scheme for the detection and localization of potholes in the pavement images. First, we classified pothole/non-pothole images using a bag of words (BoW) approach. We employed and computed famous scale-invariant feature transform (SIFT) features to establish the visual vocabulary of words to represent pavement surface. Support vector machine (SVM) is employed for the training and testing of histograms of words of pavement images. Secondly, we proposed graph cut segmentation scheme to localize the potholes in the labelled pothole images. This paper presents both, subjective and objective evaluation of potholes localization results with the ground truth. We evaluated the proposed scheme on a pavement surface dataset containing the wide-ranging pavement images in different scenarios. Experimentation results show that we achieved an accuracy of 95.7% for the identification of pothole images with significant precision and recall. Subjective evaluation of potholes localization results in high recall with relatively good accuracy. However, the objective assessment shows the 91.4% accuracy for localization of potholes.

1. Introduction

The asphalt pavements facilitate the movement of people allowing for social interaction or for getting people connected. In any part of the world asphalt pavements are a significant part of what economic growth is all about. As there is a strong correlation between a country's economic development and its road network quality, so they are also responsible for creating welfare. Poorly maintained roads restrain mobility, raise vehicle operating cost, increase accident rates, poverty, poor health and illiteracy in rural communities. Asphalt pavements should be reworked and well maintained to provide a smooth-running surface. Consistent monitoring of the asphalt pavement surfaces is required for real-time pavement maintenance.

Asphalt pavements are usually affected by some of the pavement distresses. Pavement distress is a structural disorder in the pavement surface that decreases utility or causes a drop of serviceability. In basic terms, pavement distresses are those defects which are visible on the pavement surface. Many types of defects are reported in pavement surfaces. Some of them are; block cracking, alligator cracking, transverse cracking, longitudinal cracking, depressions, joint reflection cracks, slippage, potholes, rutting and shoving [1]. Pothole is one of the distresses which is a hole in the surface of the pavement created due to the damage of the surfacing material of the pavement. In Fig. 1 we can see a few examples of potholes as variable sized bowl-shaped dumps in the pavement surface.

The process of pavement surface analysis can be divided into three stages, i.e., pavement surface data collection, distress and its type identification; and distress assessment. Data collection stage is mostly automated using a variety of equipments e.g. optical sensors for estimation of distance, laser sensors for profiling, cameras for images/videos of pavement surface and accelerometers for vibration-based approaches [2]. Manual distress identification, classification, and assessment are time-consuming and cost-effective for a real-time system. In the presence of manual analysis which is based on a clear criterion, the skill of the survey team and choice of subjective measures are mandatory for precise conclusion [3]. Presently, we can find plenty of manual or high-end equipment based approaches for potholes detection. A replacement of common low-speed manual methods is

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Fig. 1. Different appearances of potholes in the pavement surface.

proposed in [4]. A dedicated vehicle is used for the inspection of the pavement surface while moving at speed up to 60 mph. Pavemetrics [5] carried practical automation of detection of potholes using 3D data, but the system performance is not accredited anywhere [6].

Computer vision is one of the promising areas of research in technology evolution. Computer vision discipline intent to produce fruitful decisions about real-world scenes using visual data. With the increasing rate of images and videos in our daily life, computer vision is becoming more popular day-by-day to develop useful real-time applications and systems for the support of human beings. These methods can be an excellent replacement of humans thus eliminating the cost of the labor in a variety of the environments. Till now, computer vision has been used in a variety of interdisciplinary applications and domains, i.e., object detection and recognition, industrial inspection, security and surveillance, forensics, biometrics, 3D reconstruction, sports, automotive industry, activity recognition, robotics and medical imaging. This emerging branch of science has also been used for potholes detection and assessment.

An integrated system of image processing algorithms for detection and classification of various road related entities like lanes, potholes, and signs is presented by Danti et al. [7]. They considered a distinctive black color feature of potholes for their detection. The machine-learning independent algorithm segments out many non-pothole regions as potholes, it still requires an accurate filtering method to increase accuracy. The road surface is segmented into defected and non-defected areas by Koch et al. [6] for potholes detection. They used histogram shape-based thresholding along with morphological thinning and elliptical regression to extract the assumed pothole shape. Seventy (70) pavement images were used for testing and proposed scheme showed 85% accuracy. But this technique only describes the base level method for pothole detection without looking into width, depth and severity of the distress. Same scheme was further extended for pothole tracking in the video by Koch et al. in [8]. The system was focused on avoiding consideration of the same pothole multiple times but doesn't entertain the multiple potholes in the same frame. In [9], Koch et al. presented a pothole detection and assessment scheme using vision data for both 2D recognition as well as 3D reconstruction. In addition to recognition, it was useful in the depth/severity estimation of distress.

Nienaber et al. [10] presented a simple image processing based approach on real-time visual data captured using a single camera mounted on the vehicle's front windscreen. Their claimed time-efficient method has the shortcoming to deal with dirt-filled potholes. In [11], Buza et al. proposed an unsupervised pothole detection technique based on image processing and spectral clustering. Spectral clustering is used to find structure in data using spectral properties of an associated pairwise similarity matrix. They based their work on Koch et al. [6], but they improvised using Otsu's image thresholding instead of the histogram shape-based thresholding. The algorithm being cost-effective is suitable for a rough estimation of potholes. Punjabi et al. [12] introduced a simple methodology for potholes detection as well as giving an alert to the driver about them. They employed moment features on the edge images to detect potholes. But their algorithm only detected potholes and provided no information about their severity and damage assessment. Moreover, the algorithm was assumed on speed limitation of 40 km/hour for the vehicle.

A two-dimensional (2D) images-based method for pothole detection system is proposed in [13] that can be used in road management system and Intelligent Transportation System (ITS) service. The experimentation showed promising results which can be used to determine immediate maintenance required for road management system and take quick action for maintenance. However, using this method, potholes may not be detected correctly due to the shadow type and numerous pothole shapes. Poor road maintenance results in deteriorating highway network with a substantial number of potholes. A new pothole detection method using commercial black-box camera is proposed in [14]. It detects potholes over a wide range and with a low-cost solution. However, the proposed algorithm shows degraded results for the potholes which are flat or bright.

Generally, there are two visual properties for potholes; first, there are low-intensity areas in potholes that are darker than nearby pavement due to shadows. Secondly, potholes have coarser inside texture. However, the potholes are not detected accurately only with these two properties due to the lack of texture and shadow on the pavement. These challenges are addressed in [15] where they proposed a fast and straightforward pothole detection method using Spatio-temporal saliency. They used video sequences acquired from a built-in dash-cam in vehicles. Li et al. [16] proposed a scheme that integrates the processing of GPR data and two-dimensional images for efficient and accurate detection of potholes. The proposed scheme achieved an accuracy of 88%. Wang et al. [17] presented a method based on the wavelet energy field for asphalt pavement pothole detection and segmentation. Texture and gray features are integrated together to make the pothole region prominent. Efficient pothole detection is proved in results which are distinguished from patches, cracks, shadows, etc. The method achieved the overall accuracy of 86.7% for pothole detection. However, this method still has some limitations, e.g., the pothole which is smooth or bright from inside is likely to be detected as non-pothole, as well as alligator cracks, shadows, dense lane markings are very likely to be identified as a pothole. Blur images and lighting conditions will also impact the pothole detection results. Tedeschi and Benedetto [18] proposed a real-time pavement distress recognition system using Android –based mobile devices. They employed three LBP-based cascade classifiers to recognize cracks and potholes in the pavement images captured using an Android device. They have achieved an accuracy of 74% for the potholes detection. The computational time for recognition of distresses lies in the range of 1 sec to 0.327 sec depending upon the capability of the Android device. The images are captured in a very close view mode, but the algorithm may not be able to give better recognition accuracy in a realistic scenario. Koch et al. [19] presented a detailed review of computer vision techniques for defect detection and condition assessment of asphalt pavement and civil infrastructures. They highlighted the increasing use of computer vision technology in civil infrastructures e.g. bridges, tunnels, pipes and asphalt pavement. The study is more focused on vision-based approaches for analysis of asphalt pavement. They mentioned that crack properties retrieval in asphalt pavement is fully automated but natural weather conditions and environmental constraints are the challenges to develop a fully automated pavement distress analysis system. The study clearly indicates the research space for robust techniques for real-time pavement distress detection. We have also proposed histogram of oriented