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Automatic pavement defect detection using 3D laser profiling technology

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ABSTRACT

Asphalt pavement defects e.g. cracks, potholes, rutting, often cause significant safety and economic problems, thus, to automatic detect these defects is vital for pavement maintaining and management. The fact that 3D defect detection methods is superior to traditional 2D methods and manual survey methods in terms of accuracy and comprehensiveness has been widely recognized. Based on 3D laser scanning pavement data, an automatic defect detection method is proposed to detect pavement cracks and pavement deformation defects information simultaneously in this paper. Specifically, a sparse processing algorithm for 3D pavement profiles is first designed to extract crack candidate points and deformations support points, these processing is based on the assumption that the cracks are microscopic local defects while deformations are macroscopic defects in profiles. Then, the crack information can be detected by combining the extracted candidate points and an improved minimum cost spanning tree algorithm. On the other hand, the deformation depth information is acquired based on the profile standard contours which are constructed by profile envelopes and deformation support points, the accurate location and classification information of deformation defects can be obtained by the regional depth property. Experimental tests were conducted using real measured 3D pavement data containing two categories of defects. The experimental results showed that, based on the 3D laser scanning data, the proposed method can effectively detect typical cracks under different road conditions and environments, with the detection accuracy above 98%. Furthermore, different types of deformation defects including potholes, rutting, shoving, subsidence, can also be accurately detected with location error less than 8.7%.

1. Introduction

Pavement cracks, potholes, rutting, shoving and subsidence are the common forms of pavement defects [1], these typical pavement condition evaluation indicators are essential for pavement maintaining and management [2-5,7]. Some typical defects on the pavement reflect different depth and geometric features. For example, a crack often shows as an obvious linear structure [2,3,6], it generally holds a width greater than 1 mm and displays lower depth than the non-crack pavement background. A rutting is mostly resulted from the frequent traffic loads on pavement, which has certain width, depth and continuous length. Potholes [8-10] and subsidence are often featured with large area of deeper depth and deformation, and a shoving holds a certain higher elevation than normal pavement. These common pavement defects, often cause significant safety and economic problems, thus the automatic defect detection is a highly attractive problem.

In the past two decades, various of 2D imaging based systems and associated algorithms for pavement measurement have been developed for collecting in situ data to evaluate pavement conditions [2,3,11-15]. However, these traditional 2D image analysis-based pavement defect detection methods often suffer from their inability to discriminate dark areas not caused by pavement defects such as shadows and poor illumination [16–18,21]. Moreover, the 2D methods cannot detect some defects due to the lack of depth information [6]. The 3D laser scanning data has been proven its ability of obtaining the depth information and less vulnerable to lighting conditions [19,20], 3D laser technology has become the dominant approach to automatic pavement data collection in recent years [4,21,22].

Many studies were conducted to detect pavement defects based on 3D pavement data. Laurent et al. adopted an auto-synchronized laser

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scanning system to detect rutting and cracks [23]. A modification of the dynamic optimization algorithm was implemented to detect cracks on 3D pavement surfaces [18]. Hybrid procedures of matched filtering, tensor voting and minimum spanning tree were also developed for crack detection using 3D pavement data [24]. In addition, the 3D shadow model was proposed to detect various of descended patterns (i.e., cracks, joints, grooves, and potholes) on 3D pavement surface [22], however, this method required substantial manual assistance to obtain consistent results, and it was sensitive to local noises [21]. Furthermore, the 3D shadow model that applied local gradient and local dip made it hard to detect the defects of slow deformation in pavement. Pothole detection using 3D laser scanners was explored by Chang et al. [14], but the algorithm was not field-tested [4]. Other 3D pavement pothole detection methods include watershed method [4] and Kalman filter [9]. Li et al. [5] have presented a real-time 3D laser scanning system for pavement rutting, shoving detection.

Although the recent 3D pavement defect detection algorithms demonstrate some successes, the algorithms generally treat 3D pavement data as 2D pavement images or only using the 2D information contained in the 3D data [22]. More importantly, these traditional algorithms generally can only detect a single type of defect pattern on pavement surface (e.g., cracks). In high resolution 3D pavement data (depth resolution ≤ 0.5 mm, transverse resolution ≤ 1 mm), the cracks are microscopic local defect, while deformations include rutting, potholes and subsidence are macroscopic defects in profiles. Thus, most of cracks detection methods might not be applicable for the detection of other types of defect patterns. On the other hand, from the point view of practical application, it is necessary to develop methods that can detect both cracks and deformation defects from the 3D pavement data.

The biggest challenge of automatic defect detection is to consistently achieve high performance under various complex environments [21]. For the actual pavement 3D measurement system, due to the uneven surface, the vehicle vibrates up and down [18,19], and some pavement defects, each laser profile has its own characteristic in terms of profile shape, and noises. Thus, it is urgently needed to study the methods to each laser profile to extract the features of the cracks and deformation defects information simultaneously.

Aiming to detect cracks and deformation defects simultaneously from the 3D pavement data, based on the assumption that the cracks are microscopic local defect while deformations are macroscopic defects in profiles, we propose an automatic pavement defect detection method. Firstly, a sparse processing algorithm for 3D pavement profiles is first designed to extract crack candidate points and deformation support points, the algorithm based on principal component analysis(PCA) can not only obtain the microscopic information of the segments in profiles, but also the support points information. Then, the crack information can be detected by combining the extracted candidate points and improved minimum cost spanning tree(MCST) algorithm. On the other hand, the pavement deformation information is acquired based on the profile standard contours which are constructed by support points, the accurate location and classification of deformation defects can be obtained based on the regional depth property analysis.

The contents of this paper are organized as follows: Section 2 briefly describes the 3D pavement data collection system and data characteristics; Section 3 introduces the proposed methods for detecting 3D pavement crack, deformation defects; Section 4 validates the algorithms by a series of experiments; Section 5 summarizes the work.

2. 3D pavement data acquisition and characteristics

Based on the principle of triangulation [8], 3D pavement data collection system was designed, as shown in the Fig. 1. 3D pavement data collection system is used to measure the elevation profiles of the pavement, preprocessing and storing the profile data. After transforming the image coordinates to the object coordinates, that is the calibration, the measured object surface elevation data, i.e., the profiles, can be obtained.

In practical application, the 3D pavement data collection system is installed on the vehicle, two cameras each with 2 K resolution are combined to capture profiles with width about 4 m. The resolution in the transverse direction is about 1 mm (the profile sampling interval is 1 mm). The speed of pavement inspection is requires to meet the normal driving speed range of 0–120 km/h, under a depth accuracy of 0.3 mm, a depth measurement range over 0.2 m, and the sampling interval can be adjusted within 1 mm to 5 mm along the traffic direction. The 3D pavement data collection system and the installed measurement system have been shown in Fig. 1.

Calibration is an important component of the 3D measurement, in order to obtain the elevation information more accurately. Since the camera output is the relative position of the laser line in the image, not the actual elevation of the measured profile. Actually, a calibration system shown in Fig. 2 (a) is designed. The 3D laser scanning system continuously collects the image profile elevations, these are the relative image elevations, as illustrated in Fig. 2 (b). The range finder collects the moving distances of multiple measuring points, these are the relative object elevations. According to the obtained image elevations and object elevations, the corresponding relationship can be established and hence the calibration parameters can be acquired, as illustrated in Fig. 2 (b),(c). After calibration, the obtained elevation profiles can reflect the microscopic crack and macroscopic deformation information of the pavement.

Fig. 3 illustrates the 3D pavement data with defects and some profile examples. From the real measured pavement data, it is obvious that there are rich and complex pavement information contained in the high-precision 3D laser scanning pavement data, typical information including the macro-texture, cracks, potholes and rutting, etc. Moreover, due to the uneven surface, the vehicle vibrates up and down [18,19], there are inevitably included cross-slope information on real measured 3D laser scanning pavement data. The 3D laser scanning data is composed of the continuous measured profile data that reflect the relative elevation information of the pavement cross section [5,6,8,23], (the measured profile data is the elevation in profile direction, that perpendicular to the traffic direction of aforementioned vehicle system). Fig. 3 (b) and (c) shows some profile data from the 3D data in Fig. 3 (a). It can be seen that the elevation fluctuation of pavement texture, the sharp decreases of cracks, slow-varying and wide deformation caused by pavement rutting, the step-shaped elevation characteristics of the potholes, and some cross-slope information.

Because of the high accuracy, high frequency, and high dynamic characteristics of the laser scanning 3D pavement system and the various complex pavement environments, the acquired 3D pavement data has the ability to detect cracks and deformation defects simultaneously, but it also contains rich pavement scene information. Typical pavement scene information includes: pavement standard contour information, pavement defects information, texture (structure depth) information, road markings, and patching information, among which defects are mainly cracks, potholes, and rutting. Therefore, it is feasible and necessary to obtain crack information and deformation information from 3D laser scanning pavement data for pavement inspection and maintenance.

3. Pavement defect detection methodology

The asphalt pavement is mainly made up of asphalt concrete, including asphalt material in dark and grain ingredients with certain size. Generally, the grain ingredients constitute a uniform textured structure with slight undulation on the pavement — grain texture, which provides necessary friction forces for the traffic. There are mainly two kinds of pavement defects — the pavement cracks and the pavement deformation defects. Compare to the pavement without defects, these two kinds of defects both suffer from the abnormal in elevation. From the perspective of the depth magnitude and impact ranges, the