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Rahbin: A quadcopter unmanned aerial vehicle based on a systematic image processing approach toward an automated asphalt pavement inspection

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ABSTRACT

Automatic inspection of pavement cracking is a critical issue in pavement management systems. In this study, a quadcopter-based digital imaging system is introduced for collecting pavement surface data over a distressed area for visual conditions interpretation. An aerial evaluation was carried out using a quadcopter unmanned aerial vehicle (QUAV), which is a device equipped with a set of automatic systems. Since QUAV flies autonomously and has high maneuverability, it is potentially useful in a variety of conditions particularly the positions dangerous for surveillance and reconnaissance. The main purpose of this work is to design a multi-stage system for QUAV image analysis consisting of image processing, threshold selection, and classification stages. The images are transformed into a new domain; then, an adaptive thresholding is applied to build the pattern of transformed cracks; and finally, the polar support vector machine (the PSVM) is applied for interpretation of crack distress. The PSVM is an automation procedure based on the support vector machine (SVM) classifier defined in the polar coordinate frame. A Mixture of Wavelet modulus and three-dimensional polar Radon transform (3DPRT) are used for feature generation. We show that the PSVM method can be successfully applied to classify the crack and is capable of providing new features about cracking distress, threshold selection and classification. In order to show the applicability and efficiency of the proposed system and method, a test was conducted applying a variety of pavement distresses. The experimental results demonstrate that the applied system provides reliable output. In addition, the comparison of the derived information with the on-site manual quantifications revealed the potentiality of the QUAV and multi-stage system for future practice.

1. Introduction

Evaluation of pavement conditions is an essential mission in many road and transportation organizations. In the simplest method of detecting and classifying asphalt pavement cracking, the individual experts visually inspect and evaluate the pavement surface. This approach involves high labor costs and generates unreliable and inconsistent results [37]. In addition, it exposes inspectors to dangerous working conditions on highways. Destructive testing (DT) and nondestructive testing (NDT) both involve spending substantial money and time. Various attempts have been made to overcome limitations of subjective visual evaluation processes [27,29,68,71–73,75,80]. Data collection is an essential requirement for improving the quality of knowledge and making good decisions [49,59,60,83]. To collect high-quality data in a consistent and uniform way, cost-effective automated systems and modified algorithms are proposed [36,37,81]. Most pavement cracking analyzer systems employ machine vision and image processing models to automate the process and minimize the problems involved [7,10,58,89,99–101]. However, due to irregularities of pavement surfaces, there has been limited success in accurately detecting cracks and classifying crack types. In addition, most systems require complex algorithms with high levels of computing power. Although many attempts have been made to automatically collect pavement crack data, more efficient approaches are required to evaluate these automated crack measurement systems [19,26,64,79,99–101,103]. Implementation costs, processing speed, repeatability, and accuracy are among the most important controlling factors in these systems [96]. Thresholding of pavement images (or their transforms such as Radon, wavelet, etc.) is the first step for a successful high-quality distress detection and classification. Like other methods, the pavement thresholding of images involves some fuzziness. In this connection, adaptive thresholding is a useful tool to deal with this problem. For this purpose, feature selection and classification have inspired researchers to introduce a developed classifier for solving this problem.

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In the present study, three primary contributions are made: First, a QUAV-based robot platform is implemented for inspection and image acquisition. Second, a set of new methods is developed for the adaptive thresholding and feature extraction. Third, a new form of the classifier is developed to extract some rules for distress classification. By the advent of UAV technology, further attention is paid to robotic inspection and automatic assessment of pavement surfaces, as they provide a faster, more sophisticated, and safer procedure. The proposed methodology for image interpretation will enable a more efficient distress detection and evaluation with the given classification rules.

1.1. Pavement assessment tools (PAT)

Different systems are used to facilitate data acquisition using equipped vans. In general, these systems employ CCD cameras, laser sensors, or a combination of these devices [37,46]. To the best of our knowledge, nearly all commercial systems need a powerful illumination system to prepare uniform lighting conditions for capturing images. Automated road analyzer (ARAN), digital highway data vehicle (DHDV), automated distress data acquisition (ADDA), automated crack monitor (ACM), SIRANO, highways agency road research information system (HARRIS), automated distress analyzer (ADA), AIGLE RN, AMAC, Profilograph and laser, road excellent automatic logging (REAL), RoadCrack, ADVantage, PAVUE, CREHOS, and GIE are several examples of the mentioned systems [15]. Manufacturing and supporting of this equipment involves high costs with the analysis results highly depending on the circumstances and the employed sensors. Additionally, images obtained from these systems are highly discrete and automatic decisions on the type of distress are difficult and time-consuming. Therefore, more powerful tools are needed to improve the quality of images taken from the pavement.

The automatic traditional methods have many limitations such as requiring substantial time for data collection, high cost, and labor work, posing danger or inconvenience for keeping or moving in the traffic flow, and finally finding a robust method for automated interpretation. Moreover, the resulting measurement is highly subjective, which cannot meet the requirements of fully automatic interpretations.

There has always been a necessity for robotically collecting [76] and interpreting large data of the road surface for quantification and decision making. However, inexpensive, programmable, rapid, safe, and accurate assessing conditions at regular times remain the most critical drawbacks of fully automated pavement distress detection and classification.

The advantages of UAV systems are their low cost, fast speed, high maneuverability, and high safety for collecting images [67]. UAVs are already replaced over satellites and manned vehicles. Moreover, they overcome the low flexibility and high cost involved in applying aerial imagery. Compared to other existing UAV approaches, QUAV platforms have distinct advantages such as their low cost of manufacturing and maintenance, flexibility and maneuverability to work in very hard and complex surveying missions, the controllability in both autonomous and pilot mode, and manageability in abnormal stormy, windy, snowy, and rainy weather circumstances. The main objective of this work is to use a Quadcopter UAV instrument to capture pavement images.

The existing systems for capturing pavement images are able to take information in a limited width or area; however, they are not free from detection errors since they do not consider a whole region of distress. Recently, scientists have found many applications of the UAV system for aerial imaging. They believe that the experiences with the UAV systems are useful and practical for particular tasks [45,85]. These systems are tested in autonomous surveillance of damage detection and inspection [82], photogrammetric for 3D modeling, recognition of visual landmarks [69,91], remote-sensing [25], monitoring of superstructures [68], infrastructures such as pipelines, roofs, bridges, tunnels, and roads ([61, 68,75,76] [92,95]), and geometric inspection of buildings [82]. Also, Zhang and Elaksher presented a UAV-based imaging system for 3D evaluation of surface distresses in rural roads [102].

1.2. Automated pavement defect assessment

Pavement image interpretation and, especially, pavement classification have recently played a key role in automated pavement management systems and received devotion of many researchers [2,20,24,53, 74,78]. Hsu et al. [109] described a moment invariant technique for feature extraction and a neural network (NN) for crack classification. The moment invariant technique reduces a two-dimensional image pattern into feature vectors that characterize the image in terms of translation, scale, and rotation of an object in a given image. Wang and Kuchikulla [94] describe an automated system capable of real-time assessment. Using the analytical descriptions of pavement distress, they compare the images under consideration with a pre-defined database of typical crack characteristics such as location and geometry and ultimately produced surface crack indices. Lee [51] investigate image preprocessing and representation for input to an NN. Determining the real-time thresholding accurately, reliably, robustly, quickly, and automatically is of high significance in the real-time processing in almost all applications [1,6,21,50,88]. Recently, the discrete wavelet transform and its applications have become very popular in engineering areas. For instance, it has been applied in freeway work zone flow and congestion feature extraction [3,5,32,38–40,42–44], Structural System Identification [3,4, 11,41,47,48], detection and diagnosis of earthquake analysis and feature extraction for control of buildings and bridges [107], and cracking detection [104,105].

Zhou [104,105] used a two-step transformation method by wavelet and Radon transform (RT) to determine the type of the crack in a way similar to the method proposed in this research. Zhou et al. [104] proposed several statistical criteria developed in distress detection and isolation including the High-Amplitude Wavelet Coefficient Percentage (HAWCP), the High-Frequency Energy Percentage (HFEP), and the Standard Deviation (STD). These criteria are tested on hundreds of pavement images various in type, severity, and extent of distress. Experimental results demonstrate that the proposed criteria are reliable for distress detection and isolation, through which the real-time distress detection and screening is also feasible. However, the proposed method still has some shortcomings: (1) the effects of noise generated by the asphalt concrete surface and the low quality of cracks, (2) thresholding method (crisp), and (3) the classification procedure. Therefore, these three areas have become the scope of work for many researchers in recent years [10,18,23,34,56,86,108,110]. Automatic pavement crack recognition based on wiener filtering shows that this method is capable of preserving the image edge information and removing some noise through the analysis [103]. In all recent methods, thresholding plays an important role in distress detection and classification [97]. Using SVM-based distress classification, horizontal, longitudinal, and net cracks of asphalt pavement are detected. Several geometrical features are used to design a classifier based on the SVM [17]; however, more details are needed for many other protocols. The efficacy of the wavelet is demonstrated for pavement cracking analysis [58,87]. The pavement crack classification has become the scope of research for scientists in the fields of civil, computer, and electrical engineering [7,10,26,37,55, 56,58,79,89,99–101,108]. However, different lighting, low-intensity contrast conditions, and full automation still pose challenges for the pavement evaluation [89,90]. Moghadas Nejad and Zakeri [71–73] used a method for the optimum feature extraction based on wavelet-radon transform (WR) and dynamic neural network (DNN) in order to classify pavement distress. This research demonstrated that the integrated WR-DNN method could be used efficiently for the fast automatic pavement distress detection and classification. DNN threshold selection is used to enhance the accuracy of the proposed method. A two-dimensional (2D) extension of Empirical Mode Decomposition (EMD) is used for pavement distress imaging. A bidimensional intrinsic mode function