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Review and Analysis of Pothole Detection Methods

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ABSTRACT

As one type of pavement distresses, potholes are important clues indicating structural defects of the asphalt road, and accurately detecting these potholes is one of important tasks for determining proper strategies of asphalt-surfaced pavement maintenance and rehabilitation. However, manually detecting and evaluating methods are expensive and time-consuming. Thus, several efforts have been made for developing a technology which can automatically detect and recognize potholes, which may contribute to improvement of survey efficiency and pavement quality through prior investigation and immediate action. In this study, we investigate and analyze pothole detection methods which have developed and propose a potential direction of developing a pothole detection method to accurately and efficiently detect potholes.

Keywords: *Pothole, Detecting, Vibration, 3D reconstruction, 2D images, Video*

1. INTRODUCTION

Recently, damaged pavement like potholes are increasing due to the climate change such as heavy rains and snow in Korea, and thus complaints and lawsuits of accidents related to potholes are growing.

As one type of pavement distresses, a pothole is defined as a bowl-shaped depression in the pavement surface and minimum plan dimension is 150 mm [1]. Potholes can generate damages such as flat tire and wheel damage, impact and damage on the lower part of a vehicle, sudden braking and steering wheel operation, and vehicle collision and major accidents.

Figure 1 shows the number of accidents related to potholes in Korea from 2008 to July 2013.

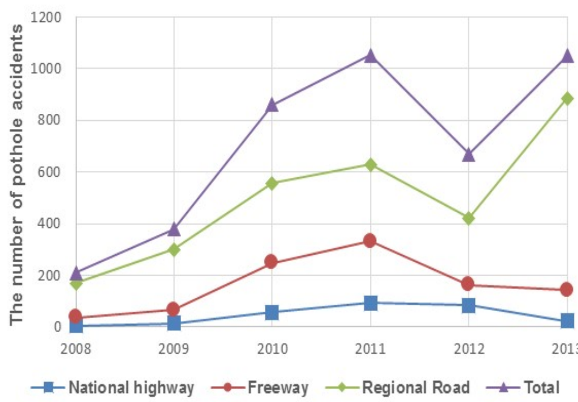

Fig 1: Number of pothole accidents in Korea from 2008 to July 2013 (MLTM, 2013)

From 2008 to July 2013, 4,233 of accidents related to potholes were happened in Korea. In 2008, total number of pothole accidents was 209 and in 2013, 1,051 of pothole accidents happened until July, which is 5 times of 2008. Among 4,223 pothole accidents, 2,961 accidents happened on regional highway, which is 70.1% of total pothole accidents.

Also, pavement distress detection such as cracks, potholes, etc. mostly performed manually is a labor-intensive and time-consuming. In order to resolve this problem, a new research is being conducted in Korea for developing a technology that can detect and recognize potholes based on images, which may contribute to improvement of survey efficiency and pavement quality by prior investigation and immediate action.

In this study, we investigate and analyze pothole detection methods which have developed until now and further propose a potential direction of developing a pothole detection method to accurately and efficiently detect potholes.

As shown in Fig 2, Existing methods for pothole detection can be divided into vibration-based methods by Yu and Yu, De Zoysa et al., Erikson et al. and Mednis et al. [2–5], 3D reconstruction-based methods by Wang, Chang et al., Hou et al., Li et al., Staniek, and Moazzam et al. [6–12], and vision-based methods by Koch and Brilakis, Jog et al., Lokeshwor et al., Koch et al., Buza et al., and Lokeshwor et al. [13–18].

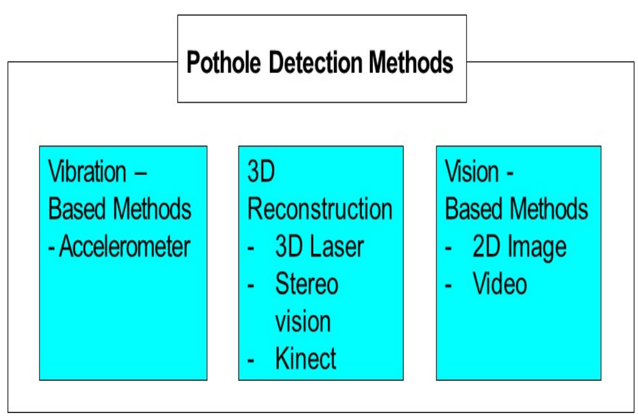

Fig 2: Classification of pothole detection methods

2. VIBRATION-BASED POTHOLE DETECTION

Yu and Yu proposed the use of recent data acquisition hardware to develop a vibration-based system for preliminary evaluation of pavement conditions [2]. The distress of the pavement such as cracks and rutting impose impacting forces on the vehicle. The pavement surface conditions can be estimated from the recorded responses of the testing vehicle when driving on the pavement. This system has the advantage of small storage requirement, cost-effective and amenable for automatic real-time data processing. However, it does not provide the complete details of distress characteristics as by video-based system. Also, the service condition of the vehicle such as tire pressure should be calibrated to compare results.

Sri Lanka has an extensive road network that spans the country and new roads are being build every day, yet even the roads in the capital city are not maintained properly. De Zoysa et al. proposed a public transportation system based sensor network (BusNet) to monitor road surface condition by adding acceleration sensor boards to the system [3]. BusNet is a sensor network initially designed to monitor environmental pollution using sensors mounted on public transport buses. The collected acceleration readings are transmitted over the BusNet to the central collection point at the Main Station. Their work, based on preliminary results, is still in process for collection of more data sets and developing an analytical model.

Erikson et al. investigated an application of mobile sensing to detect and report the surface conditions of roads [4]. They developed Pothole Patrol (P^2) system gathering data from three-axis acceleration sensor and GPS devices deployed on embedded computers in cars. They deployed P^2 on 7 taxis running in the Boston area. Using a simple machine-learning approach, they identified potholes and other severe road surface anomalies from accelerometer data. Also, they uploaded detections to central servers using opportunistic WiFi connections provided by participating open WiFi access points or, using a cellular data service, where available. Vibration-based methods could provide wrong results that the joints of road or manhole can be detected as potholes and potholes in the center of a lane cannot be detected using accelerometers due to no hit by any of the vehicle's wheels.

Mednis et al. proposed a mobile sensing system for road irregularity detection using Android OS based smartphones [5]. The selected test track is 4.4km long and the test drive session included 10 consecutive laps. The technical equipment used during the test drive session included a passenger car BMW323 touring and four different smartphones such as Samsung i5700, Samsung Galaxy S, HTC Desire, and HTC HD2. The Evaluation of selected data processing algorithms presented true positive rate as high as 90% using real world data.

Vibration-based method use accelerometers in order to detect potholes. As the advantages of a vibration-based system, these methods require small storage and can be used in real-time processing. However, vibration-based methods could provide wrong results that the hinges and joints of road can be detected as potholes and potholes in the center of a lane cannot be detected using accelerometers due to no hit by any of the vehicle's wheels (Erikson et al. [4]).

Vibration-based methods for detecting potholes can be summarized as shown in Table 1.

Table 1: Vision-based methods for detecting potholes

Authors	Methods	Equipment & experiments
Yu and Yu [2]	Using acceleration records	- ICP accelerometer, PC-oscilloscope - Test driving on I-90, USA
De Zoysa et al. [3]	Using acceleration and BusNet	- A MICAz mote with acceleration sensor - Test in Sri Lanka
Erikson et al. [4]	Using accelerometer data	- P^2 (three-axis acceleration sensor and GPS devices) - 7 taxis running in Boston
Mednis et al. [5]	Using accelerometer sensor of smartphone	- 4 Android OS based smart phones - Test drive in Riga, Latvia

3. 3D RECONSTURCTION

3D reconstruction methods can be further classified into 3D laser scanner methods by Chang et al. [7] and Li et al. [9], stereo vision methods by Wang [6], Hou et al. [8] and Staniek [10], and visualization using Microsoft Kinect sensor by Joubert et al. and Moazzam et al. [11-12].

3.1 3D Laser Scanner Methods

The 3D laser scanner uses a technique that employs reflected laser pulses to create accurate digital models of existing objects. In the study by Chang et al.[7], the accurate 3D point cloud points with their elevations were captured during scanning and extracted focusing on specific distress features by means of a grid-based processing approach. The experimental results indicate that the severity and coverage of distress such as potholes can be accurately and automatically quantified to calculate the needed amounts of filled materials.

Li et al. introduced a real-time, low-cost inspection system to detect distress features such as rutting, shoving and potholes using high-speed 3D transverse scanning techniques consisting of an infrared laser line projector and a digital camera [9]. To improve the accuracy of the system, a multi-view coplanar scheme is employed in the calibration procedure so that more feature points can be used and distributed across the field of view of the camera.

Laser scanning systems can detect potholes in real time. However, the cost of laser scanning equipment is still significant at vehicle-level and currently these works are focused on the local accuracy of 3D measurement.

3.2 Stereo Vision Methods

Wang did feasibility study to conduct comprehensive survey of pavement condition through the use of stereovision technology [6]. In this method, two digital cameras are used to cover a pavement surface. The first step is to analyze 2D images from each of the two cameras to detect and classify any cracks. The results from analyzing two image sources of the same pavement are then combined so that cracks missed by one analysis are still counted, therefore potentially achieving higher accuracy. Also, the pair of images on the same pavement surface is used to establish 3D surface model with longitudinal and transverse profiles through geometric modeling. To recover the 3D properties from given pairs of 2D images on the same pavement surface, the sequence of steps such as camera calibration, distortion correct, matching stereo points, 3D reconstruct, and profile report should be performed.

Hou et al. presented a method of applying the stereovision technique into pavement imaging to reconstruct the 3D pavement surface from a pair of images [8]. A total of four cameras were used in two pairs to collect pavement surface images across a 4-meter wide pavement (each pair of images covers 2 meters of the road). In this method, 4 steps such as calibration, distortion adjustment, matching and 3D reconstruction was involved. As an experiment platform, DHDV (Digital Highway Data Vehicle) which is a multi-system road condition survey vehicle developed by University of Arkansas and Waylink Systems Co. Also, they presented preliminary results for the feasibility of applying stereovision into pavement imaging. The resolution in 3D reconstruction can only be made as 2mm in the still environment and more than 5mm in the dynamic moving environment. They mentioned that as the next step, application of very high-precision gyro system is needed for vertical motion.

Staniek suggested the stereo vision techniques for the measurement of pavement condition with a stereo vision system attached to a vehicle for recording of the road network conditions [10]. A detailed description of the proposed solution was found in this article. As field experiments, the road section was measured on a local road with the length of 650m. The author concluded that the proposed stereo vision method might be used for evaluation of the road network conditions in Poland.

Stereo vision methods need a high computational effort to reconstruct pavement surface through the procedure of matching feature points between two views so that it is difficult to use them in a real time environment. Also, both cameras should be vary accurately aligned since the cameras may misalign and affect the quality of the outcome if there is the vibration by the vehicle motion.

3.3 Kinect Sensor

Joubert et al. [11] proposed a low-cost sensor system using Kinect sensor and a high-speed USB camera to detect and analyze potholes. At the time of this study, the project was still in its early stages. Some tests were done to determine the viability of using Kinect to examine potholes.

Recently, Moazzam et al. [12] used a low-cost Kinect sensor to collect the pavement depth images and calculate the approximate volume of a pothole. Using a low-cost Kinect sensor, the pavement depth images were collected from concrete and asphalt roads. Meshes were generated for better visualization of potholes. Area of pothole was analyzed with respect to depth. The approximate volume of pothole was calculated using trapezoidal rule on area-depth curves through pavement image analysis.

Although it is cost effective as compared to industrial cameras and lasers, the use of infrared technology based on Kinect sensor for measurement is still a novel idea and further research is necessary for improvement in error rate. 3D reconstruction methods for detecting potholes are summarized as shown in Table 2.

Table 2: 3D reconstruction methods for detecting potholes

Authors	Methods	Equipment & experiments
Chang et al.[7]	Using 3D laser scanning	- 3D laser (MENSi GS 100) - Simulation dataset & real data set
Li et al. [9]	Using 3D laser scanning	- 3D laser & digital camera
Wang [6]	Using stereo vision	- Two cameras - Feasibility study
Hou et al. [8]	Using stereo vision	- Digital Highway Data Vehicle (two computers, GPS, DMI, line scan and area-scan cameras, and laser lighting devices) - Preliminary test
Staniek [10]	Using stereo vision	- Test bench (two cameras) - Test drive in Poland
Jouber et al. [11]	Using Kinect sensor	- Kinect & USB camera
Moazzam et al. [12]	Using Kinect sensor	- Kinect sensor - Evaluation test in Rawalpindi, Pakistan

4. VISION-BASED POTHOLE DETECTION

Vision-based methods include 2D image-based approaches by Koch and Brilakis [13] and Buza et al. [17] and video-based approaches by Jog et al. [14], Lokeshwor et al. [15] and Koch et al. [16].

4.1 2D Image-Based Approaches

Koch and Brilakis presented a method for automated pothole detection in asphalt pavement images [13]. Under the proposed method, the image is first segmented into defect and non-defect regions. The potential pothole shape is then approximated according to the geometric characteristics of a defect region. Next, the texture of a potential region is extracted and compared with the texture of the surrounding non-defect region. If the texture of the defect region is coarser and grainier than the one of the surrounding surface, the region of interest is assumed to be pothole. In order to test the proposed method, it was implemented in MATLAB utilizing the Image Processing Toolbox, and images were cropped from video files captured using a remote-controlled robot vehicle prototype equipped with a HP Elite Autofocus Webcam which was installed at an altitude of about 2 feet as shown in Fig 1. Total 120 images were collected, and 50 images of them were used for training and others for testing. The resulting accuracy was 86% with 82% precision and 86% recall.

Recently, Buza et al. proposed a new unsupervised vision-based method which does not require expensive equipment, additional filtering and training phase [17]. Their method deploys image processing and spectral clustering for identification and rough estimation of potholes. The proposed method is divided into three steps such as image segmentation, shape extraction using spectral clustering, and identification and extraction. The proposed method was implemented in MATLAB and tested on 50 pothole images which were selected from Google image collection. The accuracy for estimation of a pothole surface area was about 81%. So, this method can be used for rough estimation for repairs and rehabilitation of pavements.

4.2 Video-Based Approaches

2D image-based approaches have been focused on only pothole detection and is limited to single frame, so it cannot determine the magnitude of potholes for assessment. To overcome the limitation of the above method, video-based approaches were proposed to recognize a pothole and calculate total number of potholes over a sequence of frames.

Jog et al. presented a new approach based on 2D recognition and 3D reconstruction for detection and measurement (width, number, and depth) of potholes using a monocular camera mounted on the rear of a car [14]. The method of 2D recognition built upon the previous work of Koch and Brilakis [13], and the method of 3D sparse reconstruction built upon the previous work of Golparvar-Fard et al. [19], and 3D dense reconstruction and mesh modeling was based on the dense 3D point cloud reconstruction of Golparvar-Fard et al. [19] and the poisson surface reconstruction approach. The proposed method was validated on several actual potholes using a Canon Vixia HD camera (20fps at 20mph). Future work will be real-time detection of the pothole and assessment of the total number of frames that need to be used for 3D reconstruction.

Lokeshwor et al. presented a method for automated detection and assessment of potholes, cracks and patches from video clips of Indian highways [15]. In the proposed method, first captured video clips are segmented automatically into two different types of frames category (frames with distress and frames without distress) using DFS (Distress Frames Selection) algorithm. Then, database of frames with distress is processed with CDDMC (Critical Distress Detection, Measurement and Classification) algorithm which consists of image enhancement, image segmentation, visual properties extraction, detection and classification by decision logic, and quantification. Also, the decision logic for potholes, cracks and patches were developed by three main distinctive visual properties of these distresses such as the visual texture (standard deviation), the shape (circularity), and the dimension (average width). A database of 1275 video frames with distress was selected randomly from the results obtained after applying DFS algorithm to various video clips. As results, an overall accuracy of 97% with 95% precision and 81% recall in detecting frames with potholes, overall accuracy of 94% with 93% precision and 98% recall in detecting frames with cracks, and overall accuracy of 90% with 8.5% precision and 19% recall in detecting frames with patches. If few objects such as bleedings, manholes, black colored road markings and discoloration spots appear very similar to potholes, cracks and patches, the proposed method could not deliver high accuracy.

The method by Koch and Brilakis [13] was limited to single frames and therefore cannot determine the magnitude of potholes in the frame of video-based pavement assessment. In order to complement and improve the previous method, Koch et al. presented an enhanced pothole-recognition method which updates the texture signature for intact pavement regions and utilize vision tracking to track detected potholes over a sequence of frames [16]. The proposed method was implemented in MATLAB and tested on 39 pavement video containing 10,180 frames. The resulting total recognition precision and recall were 75% and 84%, respectively. Consequently, compared with the previous method, the texture-comparison performance was increased by 53%, and the computation time was reduced by 57%. They assumed that only one pothole enters the viewport at a time, and therefore additional work is needed for considering multiple potholes in the viewport.

Vision-based methods for detecting potholes can be summarized as shown in Table 3.

Table 3: Vision-based methods for detecting potholes

Authors	Contents	Equipment & experiments
Koch and Brilakis [13]	2D image-Based approach	- Robot vehicle with a rear camera (HP Elite Autofocus webcam) - Tests for 120 images (640*480)
Buza et al. [17]	2D image-Based approach	- Tests for 50 images from google image collection
Jog et al. [14]	Video-based approach	- Canon Vixia HD camera - A few series of video stream (1440*810, 20fps)
Lokeshwor et al. [15]	Video-based approach	- 1275 video frames consisting of 283 monochromatic images (1280*960) by ARRB NSV and 992 video images(640*480) by a digital camera in India)
Koch et al. [13]	Video-based approach	- Robot vehicle with a rear camera (HP Elite Autofocus webcam) - 39 video clips (640*480, 30fps)

5. CONCLUSIONS

Accurately detecting potholes is one of important tasks for determining proper strategies of pavement maintenance and rehabilitation. However, the person manually detecting and evaluating methods are expensive and time-consuming. Thus, several efforts have been made for developing a technology which can automatically detect and recognize potholes, which may contribute to improvement of survey efficiency and pavement quality through prior investigation and immediate action.

We investigated and analyzed the existing methods for pothole detection which can be divided into vibration-based methods, 3D reconstruction-based methods, and vision-based methods.

Although the vision-based methods are cost-effective compared to 3D laser scanner methods, it may be difficult to accurately detect a pothole by these methods due to the distorted signal generated by noise since they detect a pothole through analysis of the collected image and video data. Thus, there is need to develop a pothole detection method using various features in 2D images which improve the existing pothole detection method and can accurately detect a pothole.

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