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Towards an Improved Potholes Anomaly Detection Based on Discrete Wavelet Transform and Convolution Neural Network: A Proposal

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Research Article

Abstract

Road networks in most developing nations like Nigeria, are characterized by the presence of anomalies such as potholes, speed bumps, rutting, cracks among others. This anomaly is usually caused by the poor drainage system, asphalt road exceeding their design life span, excessive traffic and a times the use of poor-quality materials for road construction. Despite efforts by appropriate agencies to rehabilitate the anomalous road networks, the anomalies still persist particularly pothole s. Thus, the need to equip vehicles with the capability of sensing and notifying drivers of the presence of this anomaly, towards making the appropriate decision of either slowing down before encountering the anomaly or avoiding it. In this regard, this paper presents the preliminary results obtained towards the development of a robust vision processing based approach for potholes anomaly detection that is independent of the illumination intensity during data acquisition. The proposed approach utilized the median filter for denoising the image, discrete wavelet transforms in deblurring and preserving the edges of the anomaly, while canny edge detection algorithm was used for segmenting the image and extracting features used in training a Convolutional Neural Network for potholes anomaly detection and classification. The preliminary results obtained indicate the potholes anomaly were detected and classified accordingly with about 96% accuracy, 95% precision and low false alarm rate of about 5%. This indicates the potential of the proposed approach to be used for real-time potholes anomaly detection and notification system. Also, it can be incorporated into manned and unmanned vehicles towards aiding navigation in such an anomalous road terrain.

Keywords
Anomaly, Canny-edge-extractor, Convolutional Neural Network, pothole and road.

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1. Introduction

.Road network plays a major role in the economy growth and development of any nation (Bello-Salau *et al*., 2015). This is attributed to the fact that it is one of the major means of transportation that allow the vehicular movement of goods, services and human from one location to another. It is important to ensure that the road networks are in good conditions, by continuous monitoring of the road surfaces. For decades, manual inspection of the road surface has been widely used by concern agencies for monitoring road surface conditions (Bello-Salau, Aibinu, Onumanyi, Ahunsi, *et al*., 2018; Bello-Salau *et al*., 2019). This enables them to plan and priorities road maintenance and repairs. However, the use of such approach has been reported to be less effective, prone to error, time wasting, resources and manpower. In other to overcome this challenge, there is a need to equip vehicles with technology capable of monitoring and detecting anomalies on asphalt road surfaces (Bello-Salau, Aibinu, Onumanyi, Onwuka, *et al*., 2018). Prevalent in this vehicular technology is the use of a vibrational-based approach (Bello-Salau, Aibinu, Onumanyi, Onwuka, *et al*., 2018; Salau et al.; Sattar, Li, and Chapman, 2018), 3D reconstruction-based approach (Zhou et al., 2016), and the Vision-based approach (Gopalakrishnan, Khaitan, Choudhary, & Agrawal, 2017; Tedeschi & Benedetto, 2017). This road surface anomaly sensing is geared towards improving driving comfort, reducing anomalous induced traffic accidents and reducing the rate of wear and tear of vehicle as they ply such anomalous road network.

Road anomalies on asphalt road occur as a result of the roads exceeding their maximum lifespan, the use of poor-quality materials for construction, poor drainage systems, excessive road traffic and failure to comply with the standard road construction specification. These anomalies can be in the form of potholes, speed bumps, rutting and cracks (Nhat-Duc, Nguyen, & Tran, 2018). Though, prevalent among these anomalies in developing nations like Nigeria is the potholes, which can be describe as a bowl-shaped hole on asphalt pavement road surfaces with about 40mm or more depth (Bello-Salau *et al*., 2015). These anomalies have contributed to the increasing anomalous induced road traffic accident. In addressing this challenge, the vision-based approaches for sensing road anomalies has been widely used and reported (Azhar, Murtaza, Yousaf, and Habib, 2016; Koch and Brilakis, 2011; Ouma and Hahn, 2017). This is attributed to its simplicity, low implementation cost and improve accuracy of detection, when compared to other similar approach such as the vibrational-based techniques. However, the accuracy of most vision-based approach depends on light intensity and time of the day which data is acquired that degrade detection accuracy and general performance of such approach. Thus, in this paper, a vision-based approach that entails the used of median filter, discrete wavelet transforms and canny edge extractor algorithm for extracting features that was used in training the Convolutional Neutral Network towards improving the performance accuracy of potholes anomaly detection, precision and minimize false alarm is presented. The performance of this proposed approach is independent of the illumination intensity during data acquisition process. The rest of the paper is structured as follows, section II presents an overview of related work, section III presents the proposed methodology, while preliminary results obtained is presented and discussed in section IV and conclusion is drawn in section V.

2. Related Work

This section presents an overview of some documented vision-based approaches for road surface conditions monitoring and anomaly detection. The performance of most reported vision-based approaches, are limited by the illumination intensity during data acquisition and the use of a single threshold value for anomaly detection during the algorithmic processing of the acquired road surface image datasets. An approach based on an OpenCV library incorporated into an android mobile phone for real-time road anomalies detection was reported in (Tedeschi & Benedetto, 2017). A local binary pattern (LPB) cascade classifier was used for training based on acquired image datasets in Rome containing both cracks and potholes images. The developed classifier was incorporated into an android mobile application for real-time sensing and detection of road anomalies. An improved performance score of about 0.7 each for the precision, recall and f-measured was obtained. However, the performance of the reported technique depends on the quality of the datasets used for training the LBP classifier. Furthermore, there is need to investigate the used of other pre-processing techniques towards improving the performance of the classifier.

A deep convolution neural network (CNN) based technique for road anomalies detection was presented in (Xia, 2018). It involved the use of label data in training and testing of the algorithm. The image segmentation was achieved by the use of a conditional random fields (CRF) approach. A single shot multibox detector was used for the road anomaly detection and classification using the CNN. Results obtained shows that the proposed technique was able to detect cracks and potholes with some considerable accuracy level. However, there is need for further preprocessing of the acquired image data set towards catering for the local minima issue. In addition, there is need to minimize the effect of different illumination conditions experience during data acquisition that affect the performance of the proposed technique.

A supervised learning based approach, that entails the use of Artificial Neural Network (ANN) and Least Square Support Vector Machine (LS-SVM) for road anomaly detection and classification based on label data sets that was used for training and testing was presented in (Hoang, 2018). A steerable filter was used for feature extraction. Thereby, creating a salient map (SM) for road anomaly detection. This was achieved by isolating and differentiating between the foreground and background images. Though some promising results were reported, but the manual tuning of the standard deviation using a trial and error value may hinder the performance of the proposed technique. Similarly, an approach that involved the preprocessing of sensed road anomalies datasets based on bilinear interpolation, which was denoised by a non-local means method and enhanced via histogram equalization for automatic road distress detection and classification was proposed in (Siriborvornratanakul, 2018). Morphological operation was performed on the binarized output image from the histogram equalization. Results obtained showed the possibility of using the proposed technique for road anomaly detection. However, the performance of the proposed approach is hinder if the acquired pothole image was sand filled.

A wavelet energy field based on morphological processing technique and geometric criterion for pothole anomaly detection from acquired pavement images was proposed in (Wang, Hu, Dai, & Tian, 2017). Edges of detected potholes anomaly were extracted using random markov field-based segmentation model. Features of the image texture and gray were incorporated together in the developed energy field, in mapping region of the pavement image with potholes anomaly. Reported result indicate a better performance compared to (Koch & Brilakis, 2011) in terms of accuracy of detection, precision and recall with 86.7%, 83.3% and 87.5% respectively. Nevertheless, light illumination intensity affects the performance of the proposed approach leading to high false alarm rate. In addition, there is need to reduce the algorithm complexity towards its suitability for real time application.

A 3D reconstruction-based method that used 3D laser scanner, stereo vision and visualization based on Microsoft Kinect sensor was reported in (Jahanshahi & Masri, 2012). The proposed approach shows some promising results with a considerable level of detectionaccuracy. Though, with a tradeoff of high computational cost. Furthermore, the illumination intensity during data acquisitions may hinder the detection accuracy of the proposed techniques. Similarly, Koch in (Koch & Brilakis, 2011), an approach that involve the segmentation and classification of acquired road surface image data into defect and non-defect was presented. Subsequently, the texture inside a potential defect shape was extracted and compared with the texture of the surrounding non-defect road to determine if the region of interest represents an actual pothole. Bubenikova proposed an unsupervised and automatic pothole detection using a 2D vision-based approach in (Bubeníková & Halgaš, 2012). Histogram shape-based thresholding approach was used for separating defected and non-defected regions in road acquired road images. However, the performance of the proposed approach depends on the light illumination during data acquisition.

3. Proposed Methodology

This section presents the proposed technique for the automated potholes road anomaly detection. The entire process was categorized into three stages, namely: the acquired data pre-processing stage, the segmentation stage and the detection and classification stage as summarized in

Figure 1. The data acquisition stage entails the capturing of different road surface conditions image with the presence of potholes anomaly, bumps, rutting cracks and even smooth road. This become necessary as result of lack of road surface conditions image data that can be used to test the proposed algorithm. We note that a database containing road surface conditions was reported in (Bello-Salau, Aibinu, Onumanyi, Ahunsi, et al., 2018). However, the datasets contained in the database were only one-dimensional signals and not images. Thus, necessitating the need for data acquisition stage. A Huawei Y9 mobile phone camera with 13MP+2MP dual back camera was used for the image data capturing during drive test along the test road, at Eastern by-pass, Minna, Niger state, Nigeria. The choice of the Huawei Y9 camera was prompted due to its high resolution that ensure the clarity of the captured image. Data were acquired at different time of the day so as to cater for effect of light illuminations during data capturing. A total of 400 different image datasets were captured, comprising of potholes, bumps, cracks and smooth road images. The captured images were pre-processed by resizing the size of all captured test data to a size of 400 * 300 pixel. This, become necessary towards minimizing the computational time of the proposed algorithm. The captured RGB image data were converted to grey images and fed into a 3 x 3 kernel median filter in order to denoise the captured images while preserving its edges.

The preserved edges of the image were enhanced by the application of a 2-D discrete wavelet transform (DWT) that decomposes the image into both the lowpass and highpass filter component. The 'Harr' mother wavelet was used because of its high preserved edges of the filtered pothole images when compared to 'dB', 'symlet' and other dual basis functions. An approximate and detail coefficient of the inputed images were obtained from the lowpass and highpass filters. The output of the approximate coefficient in the DWT LL sub-band, which contain more detail information was segmented using a canny edge detection algorithm. The choice of this algorithm was motivated by its inherent ability to accurately detect and extract edges of images. We note that an experimental threshold value of 0.75 was used for the image edge extraction, as values outside this range perform poorly. Figure 2, presents flowchart of the proposed pre-processing and segmentation process implemented in MATLAB towards an improved road anomaly detection and classification.

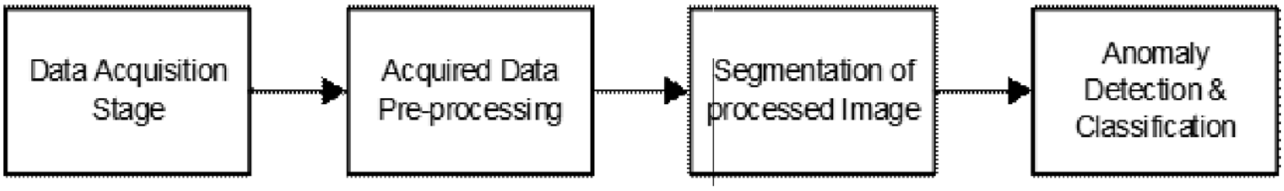

Figure 1: Block Diagram of the developed Potholes Road Anomaly Detection System

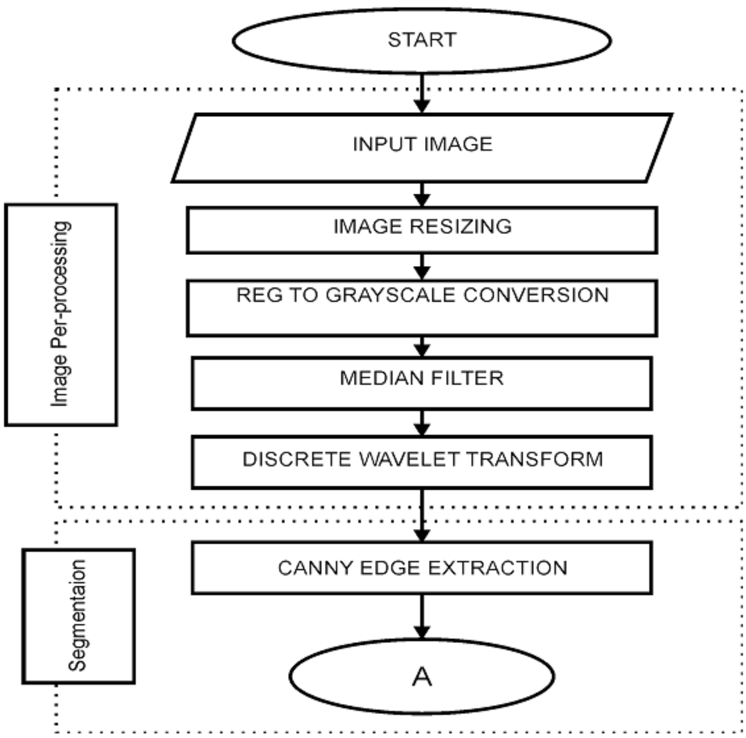

Figure 2: Proposed pre-processing and Segmentation Approach

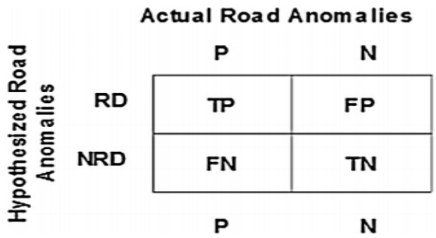

Figure 3: Confusion Matrix (Bello-Salau, Aibinu, Onumanyi, Onwuka, *et al*., 2018)

The output of the segmentation process was fed into a pretrained convolution neural network (CNN) known as ResNet50, that detect and classify the anomaly present in the input image accordingly. The choice of this CNN approach was motivated by its simplicity and performance with minimal false alarm when compared to other pretrained network. We note that 70% of the pre-processed and segmented data was used for training the deep learning ResNet50, while 30% was used for testing and validation. Road anomaly were detected by the algorithm and classification was done accordingly into pothole and smooth road class. The input preprocessed and segmented images with road line mark were classify under the smooth road class. The confusion matrix table presented in (Bello-Salau, Aibinu, Onumanyi, Onwuka, et al., 2018) as shown in Figure 3, was used for computing the probability of detection, precision and the false positive rate using equation (1), (2) and (3) respectively. Basically, for an already labeled image dataset, if a road anomaly exists being term positive (P), and the algorithm was able to detect and classify the anomaly as potholes or smooth road, then a True Positive (TP) is declared. But, if wrongly detected and classify as smooth road (non-anomaly (NRD)), then a false negative (FN) is declared. Furthermore, if the labeled image data sample is a smooth road with non-anomaly (N), and the algorithm was able to detect and classify appropriately as smooth road (non-anomaly (NRD)), then a True Negative (TN) is declared, otherwise, a False Positive (FP) is declared. The process of detection and classification is summarized by the flowchart presented in Figure 4.

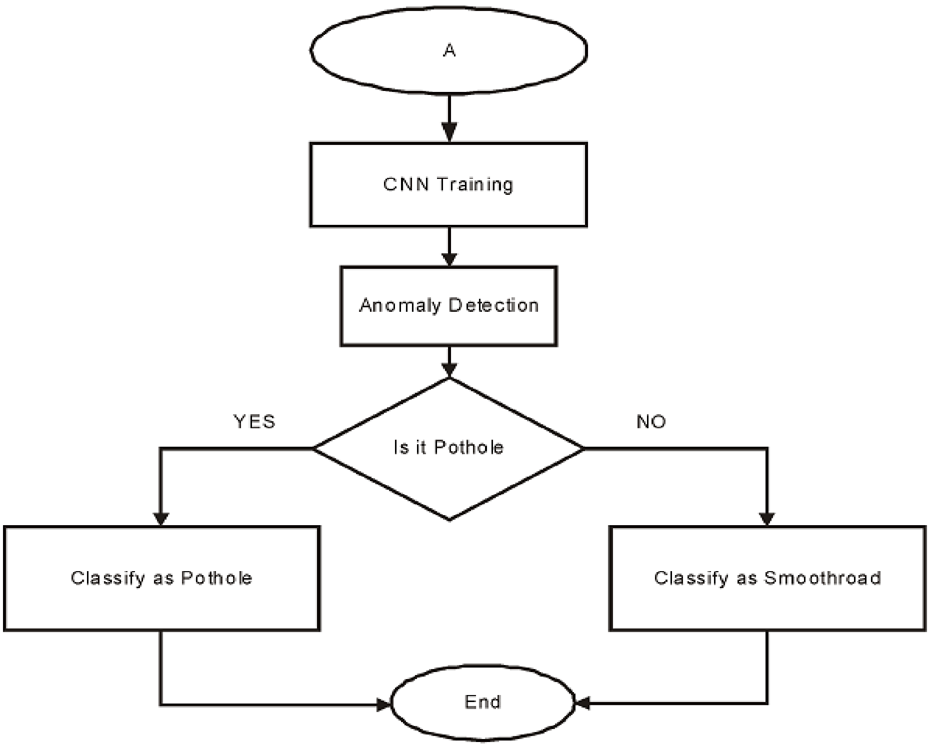

Figure 4: Flowchart of the CNN Process of Detection and Classification

$$Accuracy = \frac{TP + TN}{P + N} \quad (1)$$

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$FPR = \frac{FP}{N} \quad (3)$$

4. Results and Discussion

In this section, we present the preliminary results obtained from the simulation in MATLAB towards the development of an improved potholes anomaly detection and classification with possible incorporation into manned and unmanned vehicles. Sample images of some of the raw data with different depth of potholes anomaly captured during the data acquisition phase is presented in Figure 5. Observed generally, that there occurs a depression on all surfaces of the captured images shown in Figure 5. We note that this depression is being referred to as potholes, which contributed greatly to the number of road traffic accidents recorded within the country. This raw image was preprocessed and segmented using the median filter and the discrete wavelet transform discussed in section III. Figure 6, presents a typical scenario of an input raw data (see Figure 6a), which was denoised using the median filter and the corresponding output (see figure 6b) was fed into the discrete wavelet transform. Observed that the blurriness in the median filtered image (see Figure 6b) was improved upon and the edges of the pothole anomaly become sharper as seen in the output of the DWT shown in Figure 6c. However, the output of the segmented image using the canny edge extractor was able to extract edges of portion of the image with the road anomaly from the background as shown in Figure 6d. This was made possible by the utilization of discrete wavelet transform that help preserve and enhance the edges of the processed image towards improving the performance of the CNN for accurate detection and classification. The average performance of the output of the CNN using accuracy of detection, precision and false alarm rate as metrics computed using equation (1), (2) & (3) respectively was about 96% accuracy, 95% precision and about 5% false alarm. This result shows an improved performance when compared to that reported in (Koch and Brilakis, 2011).

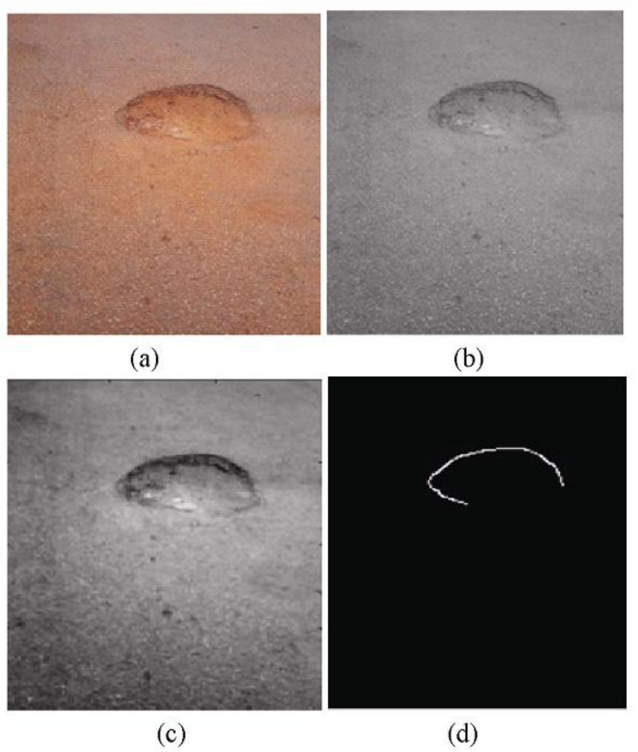

Figure 5: Sample images with potholes anomaly in the acquired raw data

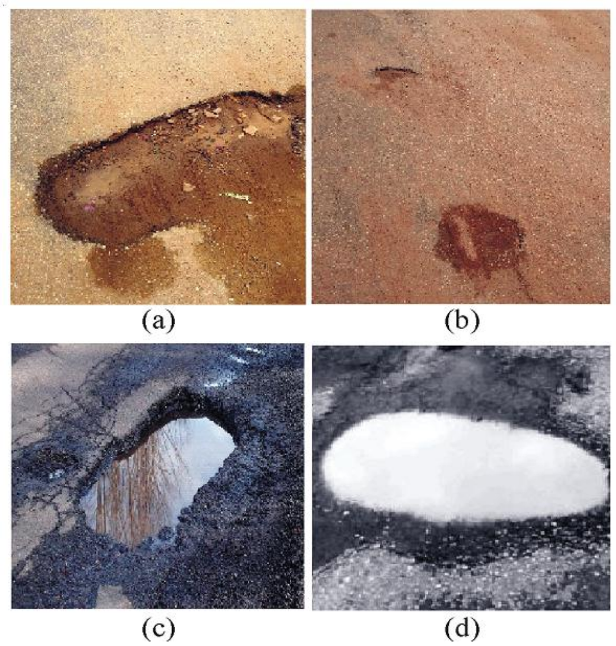

Figure 6: Sample images with potholes anomaly in the acquired raw data

5. Conclusion

An approach aims towards improving road anomaly detection and classification was presented. This entailed using a median filter for denoising acquired road surface image, applying a discrete wavelet transform towards deblurring and preserving edges of the input image with road anomalies. A canny edge detection algorithm was used for the segmentation of the input image, which was subsequently fed into a ResNet 50 pretrained CNN network for detection and classification. Preliminary experimental results obtained showed a potential for the proposed approach to improve pothole anomaly detection accuracy and precision with minimal false alarm. Future work will explore the possibilities of extending the approach for real-time potholes anomaly detection, and perform extensive performance comparison with other similar approach. This proposal can find application in aiding navigation in manned vehicle and possible integration into autonomous vehicle.

References

Azhar, K., Murtaza, F., Yousaf, M. H., & Habib, H. A. (2016). Computer vision based detection and localization of potholes in asphalt pavement images. Paper presented at the 2016 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE).

Bello-Salau, H., Aibinu, A., Onumanyi, A., Ahunsi, S., Onwuka, E. and Dukiya, J. (2018). Development of a road surface condition monitoring and database system. Paper presented at the 2nd International Conference on Information and Communication Technology and Its Applications (ICTA 2018), Federal University of Technology, Minna, Nigeria.

Bello-Salau, H., Aibinu, A., Onumanyi, A., Onwuka, E., Dukiya, J. and Ohize, H. (2018). New road anomaly detection and characterization algorithm for autonomous vehicles. Applied Computing and Informatics.

Bello-Salau, H., Aibinu, A., Onwuka, E., Dukiya, J., Bima, M., Onumanyi, A. and Folorunso, T. (2015). A new measure for analysing accelerometer data towards developing efficient road defect profiling systems. Journal of Scientific Research & Reports, 7(2), 108-116.

Bello-Salau, H., Aibinu, A., Wang, Z., Onumanyi, A., Onwuka, E. and Dukiya, J. (2019). An optimized routing algorithm for vehicle ad-hoc networks. Engineering Science and Technology, an International Journal.

Bubeníková, E. and Halgaš, J. (2012). Application of image processing in intelligent transport systems. IFAC Proceedings Volumes, 45(7), 53-56.

Gopalakrishnan, K., Khaitan, S. K., Choudhary, A., & Agrawal, A. (2017). Deep Convolutional Neural Networks with transfer learning for computer vision-based data-driven pavement distress detection. Construction and Building Materials, 157, 322-330.

Hoang, N.-D. (2018). An artificial intelligence method for asphalt pavement pothole detection using least squares support vector machine and neural network with steerable filter-based feature extraction. Advances in Civil Engineering, 2018.

Jahanshahi, M. R. and Masri, S. F. (2012). Adaptive vision-based crack detection using 3D scene reconstruction for condition assessment of structures. Automation in Construction, 22, 567-576.

Koch, C., & Brilakis, I. (2011). Pothole detection in asphalt pavement images. Advanced Engineering Informatics, 25(3), 507-515.

Nhat-Duc, H., Nguyen, Q.-L. and Tran, V.-D. (2018). Automatic recognition of asphalt pavement cracks using metaheuristic optimized edge detection algorithms and convolution neural network. Automation in Construction, 94, 203-213.

Ouma, Y. O. and Hahn, M. (2017). Pothole detection on asphalt pavements from 2D-colour pothole images using fuzzy c-means clustering and morphological reconstruction. Automation in Construction, 83, 196-211.

Salau, H. B., Onumanyi, A. J., Aibinu, A. M., Onwuka, E. N., Dukiya, J. J. and Ohize, H. A Survey of Accelerometer-Based Techniques for Road Anomalies Detection and Characterization. International Journal of Engineering Science and Application, 3(1), 8-20.

Sattar, S., Li, S., and Chapman, M. (2018). Road surface monitoring using smartphone sensors: a review. Sensors, 18(11), 3845.

Siriborvornratanakul, T. (2018). An Automatic Road Distress Visual Inspection System Using an Onboard In-Car Camera. Advances in Multimedia, 2018.

Tedeschi, A., and Benedetto, F. (2017). A real-time automatic pavement crack and pothole recognition system for mobile Android-based devices. Advanced Engineering Informatics, 32, 11-25.

Wang, P., Hu, Y., Dai, Y., and Tian, M. (2017). Asphalt pavement pothole detection and segmentation based on wavelet energy field. Mathematical Problems in Engineering, 2017.

Xia, W. (2018). An Approach for Extracting Road Pavement Disease from HD Camera Videos by Deep Convolutional Networks. Paper presented at the 2018 International Conference on Audio, Language and Image Processing (ICALIP).

Zhou, S., Shen, W., Zeng, D., Fang, M., Wei, Y. and Zhang, Z. (2016). Spatial–temporal convolutional neural networks for anomaly detection and localization in crowded scenes. Signal Processing: Image Communication, 47, 358-368.