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Intelligent Detection of Potholes Using SSD Algorithm and Auto-Alert Notification System for User

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Abstract. Potholes are cracks on the road's surface that leave a hole behind it. Reporting potholes to accountable bodies at an early stage can save many lives. Therefore, timely inspection and maintenance of potholes are required for smooth transportation. Traditional pothole detection methods are labor-intensive and time-consuming. This research focuses on such gaps and presents an intelligent detecting system that uses a smartphone camera, sensors, and gyroscope for real-time detection of potholes. The proposed model covers two essential functions: i). automated identification of potholes, and ii). notifying users to escape probable accidents. The "Single Shot Multi-Box Detector (SSD)" technique trains the pothole image datasets. For developing the dataset, pothole images are taken and labeled with TensorFlow object detection API. The method achieved 90% accuracy in detecting potholes in used image datasets. Study outcomes can help stakeholders get road profiling information and alerts about potholes for smooth road transportation.

Keywords. Road transportation; pothole detection; user notification; single shot multi box detector; mind map.

1. Introduction

The maintained road infrastructure is necessary for a nation's social and economic prosperity [1]. The traffic flow parameters like speed, density, and volume also affect the drivers' road safety [2]. In India, drivers have difficulty identifying manholes, bumps, and other hazards, leading to catastrophic road transportation mishaps. Potholes are cracks that occur on a road's surface and leave a hole behind it. The potholes affect drive comfort, fuel consumption, the safety of road users, and road maintenance [3]. Potholes can be classified into small, medium, and large. Potholes smaller than 25mm deep and 200mm wide can be classified as small, while sizes between 25mm to 50mm deep and 500mm wide can be considered medium potholes. Potholes greater than 500mm deep and 500mm wide are classified as significant.

Potholes cost governments and individuals billions of dollars yearly. Having a real-time pothole detection system deployed in automobiles can inform drivers about the potholes beforehand. This will assist drivers to avoid potholes and prevent accidents. Therefore, it is necessary to carry out timely inspection and maintenance of potholes to avoid road accidents and to prevent loss of human life and resources.

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Real-time pothole detection is a challenging process that needs a comprehensive solution. Information on road deterioration is critical for cost-effective maintenance [4]. Warning-based monitoring technologies can facilitate safety warnings for users to prevent critical road conditions [5]. Existing methods of pothole detection are labour-intensive, time-consuming and increased expenses for materials and equipment [1][6]. There are multiple obstacles in identifying a pothole, like low visibility of potholes from a long distance or in a night scenario, narrow width of potholes, accuracy in the detection process, complexity in detection systems, etc. To resolve such research gaps, this research focuses on the following objectives –

- To propose a mind map framework to understand the detailed approach to the pothole detection process.
- To propose a model for automated identification of potholes and to notify drivers to escape probable accidents.

From the practitioners' perspectives, the proposed model contributes towards two essential functions: intelligent identification of potholes and notifying drivers to escape probable accidents. The suggested technique is affordable for detecting potholes since it utilizes low-cost sensors and mobile cameras. The integration of mobile applications can give timely notifications to users about potholes. Regarding theoretical contribution, the developed mind map enriches existing knowledge on various pothole detection methods like camera-based, sensor-based, and 3D reconstruction-based detection methods. The proposed mind map contains integrational aspects of pothole detection like road 4.0 technologies, data modeling, image-based detection, vibration-based detection, and 3-D reconstruction methods. The study can help various stakeholders associated with the transport sector by providing pothole mapping data for maintenance and repair.

2. Review of literature

Previous works have discussed automatic pothole-detecting systems based on a variety of sensors. The previous approaches can be classified into three main categories: A). camera-based methods, B). sensor-based methods, and C). 3D reconstruction-based methods.

2.1 Camera-based pothole detection

Camera-based techniques are suitable for precisely identifying potholes across a large region at a low cost. Many techniques usually depend on 2D pictures. A camera can assess road conditions with high accuracy. However, identifying potholes through camera data still needs to be refined. Fan et al. [7] have proposed Convolutional Neural Networks (CNNs) and adaptive thresholding techniques to detect potholes on road surfaces. Jo et al. [8] presented a standard camera-based pothole detection. The camera is installed on the windshield of a car to recognize a pothole. A crowd strategy was developed to collect data on a large scale from multiple cars operating on the roads.

In the last few years, low-cost digital cameras and advanced digital image processing methods have proved essential for pothole surveys. The use of smartphones is becoming more common for road inspections. Numerous algorithms based on computer vision are developed in the literature to cope with the challenges of pavement pothole recognition. 2D pictures have been utilized to identify potholes. A dataset of 1500 pothole images was created on Indian highways to train CNNs for pothole detection.

A camera fixed on the rear part of a car was used to create a new approach for detecting and measuring pothole size, number, and depth. Using video footage of Indian highways, [10] developed automated identification of potholes, fractures, and patches. Using the "Distress Frames Selection algorithm," original video footages are separated into two unique frame categories. Potholes, black-coloured road signals, and discoloured regions are likely potholes.

2.2 Sensor-based pothole detection

Road safety-related data can be captured using various sensor technologies and data-driven techniques. Accelerometers have been deployed widely for pothole detection because of their low cost. Modern data-collecting technology was used to construct a sensor-based system for the early determination of pavement problems. The system offers the advantages of low storage requirements, low cost, and adaptability for automated real-time data processing.

Smartphones can collect data from accelerometers and GPS to train deep-learning models [1]. Vibration-based approaches might yield false findings that a manhole can be misrecognized as a pothole. The accuracy is comparatively less than other sensors-based methods like cameras and lasers, as potholes can only be recognized when a vehicle's wheels move over a pothole. The sensor-based methods are inexpensive and easy to implement.

2.3 Detection using 3D reconstruction methods

The 3D reconstruction method includes a 3D laser scanner for scanning road surfaces to detect anomalies [1]. 3D projection has steadily become an actuality with the advancement of digital image analysis, computer animation, machine learning, and 3D imaging technology. The camera-based approach might contain a single image or several images. This method uses a single picture or combination of pictures to capture the pothole's height, color, and structure to rebuild the entire picture. This strategy offers the benefits of low cost and quick analysis. In comparison to other approaches, laser scanning provides superior detection performance. This approach eliminates the challenges of camera calibration and picture feature recognition.

The 3D laser scanner is a technology that generates exact digital reconstructions of the natural world by using reflected laser pulses. Cost-effective and real-time monitoring was proposed to identify potholes [11]. While calibrating the procedure, a multi-view coplanar technique was used to increase system accuracy by allowing additional feature points to be used and scattered throughout the camera's field of view. Vision-based techniques are inexpensive compared to 3D laser technologies.

Stereovision technology with pavement images was discussed to recreate a 3D pavement area from the combinations of photographs. The 3D laser scanning uses reflective laser pulses for building models. Stereo vision uses two digital cameras to construct 3D images of objects [12]. The visualization techniques use a Kinect sensor and USB camera to analyze road surfaces.

Stereo vision methods need much processing to rebuild a pavement surface by matching feature points between two images. Previous research identified potholes through vibrations recorded from an accelerometer while traveling over one. Such systems lack real-time data processing and do not alert the drivers. The research tries to resolve such gaps and presents a pothole-detecting system that uses a smartphone camera, sensors, and gyroscope for real-time detection of potholes in a cost-effective manner.

3. Research Methodology

3.1 Mind mapping

The mind map can help understand various technologies employed for pothole detections and future developments in this domain. A mind map is a method that provides multi-dimensional connected visual insights and structured information around the chosen problem or idea [13]. The mind map technique is more flexible and has various benefits as a research methodology.

The mind map presents information in expandible topic trees to visualize insights from bibliometric analysis and experts' opinions. A total of 9 field experts have been consulted. The experts were identified using purposive sampling based on their expertise, diverse perspectives, and domain knowledge. The experts specialized in road 4.0, image processing, embedded systems design, emerging technologies, sensor technology, advanced communication, adaptive control, and mobile app development. The procedure was discussed with all experts in a plenary session at the beginning of the Mind map session.

Experts were contacted through email, and online meetings were conducted to gain input. At the beginning of the session, the facilitator discussed the problem statement and literature review. The study uses MindManager X5 software for the digitalization of the mind map. Mind mapping allows one to view concepts holistically and assess information about complex problems with reasoning. Mind maps have been utilized in different domains like electric vehicle design [14], cognitive learning outcomes [15], and designing smart cities [16].

3.2 Pothole detection using SSD method

The study uses single-shot multi-box detector (SSD) that helps devices with low computational capabilities, like smartphones, to perform better than R-CNN and YOLO (you only look once). SSD algorithm has higher detection accuracy and presets a fixed number of default boxes of different scales and aspect ratios at each position of the extracted feature map. The network can directly perform intensive sampling on the feature map to extract candidate boxes for prediction [17].

The data was collected through smartphones, and images were labelled manually using the labelimg tool. The study uses Android Studio, python programming, TensorFlow, and compute unified device architecture (CUDA) to develop a mobile app for pothole detection. Android Studio provides a platform to build apps for Android devices. Users can build, run, and debug programs using this platform. TensorFlow is an open-source software library used for deep neural network training. Labelimg tool is used to annotate image datasets. Annotations can be saved into XML files that can be converted into TFRecord. CUDA is a parallel computing platform and API architecture that enables the usage of graphics processing units (GPUs) for general-purpose tasks. CUDA provides numerous benefits over graphics API-based general-purpose Computing on GPUs.

The rear camera records continuous movement, and each frame is sent to the trained custom object detection model. Pothole photos are taken and labeled for developing the dataset with the TensorFlow object detection API. SSD is an algorithm that is used to identify objects. It generates bounding boxes around identified objects and confidence scores for each one. The convolutional filter is used to forecast object categories to detect low-resolution pictures with higher accuracy. The SSD model creates predictions at multiple scales from feature maps of varied pothole sizes for higher accuracy [18].

The complete dataset was classified into three parts: a training set, a validation set to identify parameters during training, and a test set to evaluate results. Over 300 pothole images were taken to train the model to detect potholes. The images were taken under various lighting situations, road conditions, forms, and sizes (Fig. 2).

Labeling, an open-source graphical annotation tool, is used for labeling images. It is helpful for item localization or detection, and it can construct a rectangular box around the targeted objects. Data augmentation is a technique to improve the training dataset to avoid overfitting. Commonly used methods include flipping, rotation, blur, Random zoom, vertical and horizontal shifts (translations), and brightness changes. Each technique produces several images from one image, increasing the number of instances. As a result, the model trains on more images, which helps to improve accuracy [18].

An XML file with the annotations has been created for collected images using Labelimg. The XML file and all pictures have been transferred to TensorFlow. The SSD technique was used to train the pothole dataset. In the real-time testing stage, a rectangular box with a confidence interval appears whenever a pothole is detected (Fig. 3). SSD object detection framework uses a Mobile Net feature extractor that requires a low CPU load and memory storage network to detect and classify the objects [4].

4. Results

4.1 Proposed Mind Map for Pothole Detection

A mind map framework has been proposed to understand the different approaches and processes of pothole detection (Fig. 1). The experts validate the mind map framework, which could be employed to design an efficient pothole-detecting system. Mind maps reflect experts' thought processes and ideas collaboratively and look for patterns when concisely synthesizing information to present relations. The Primary branch radiates from the central node and links directly to map the problem. The sub-branches further expand the primary branch. The mind map configurations can be analyzed regarding connections among primary concepts to examine thought processes and patterns [14].

In the mind map (Fig. 1), the parent central node is pothole detection, connected to various other nodes. The proposed mind map contains integrational aspects of pothole detection using Road 4.0 technologies like augmented reality, vehicular networking, interactive road environment, and big data applications in transport systems. Big data can help develop route profiles and analyse previously collected data through sensors and other sources. Data Modelling can be done using Machine learning algorithms, statistical methods, and computational intelligence.

The smartphone can provide cost-effective input data of large road networks for processing [4]. With the help of Google-based map integration, the travel route can be identified, and images of the road should be captured the dataset of images contains both potholes and road images without potholes.

The image-based detection is further divided into sub-nodes like features extraction, segmentation, smoothing, enhancement, and classification using random forest, decision tree, SVM, and ML-based algorithms for detecting potholes by creating an intelligent system. The vibration-based detection method can measure acceleration across the X, Y, and Z axes. Sensors already present in mobile phones, like accelerometers and gyroscopes, can be used to detect the changes in vehicle axes for pothole detection. The processed data after pothole detection can be sent to relevant stakeholders such as transport companies, providing pothole mapping data, which can be integrated with Google Maps and to its data development team.

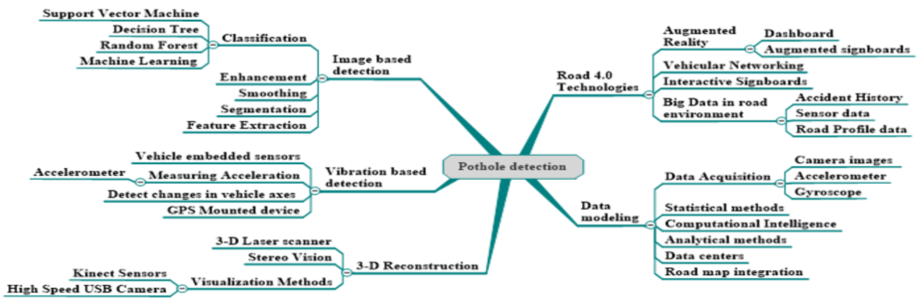


Figure 1. Proposed Mind Map for Pothole Detection

Computer vision, image processing, and machine learning can be used to detect and extract features of potholes [3]. Many advanced algorithms like deep neural networks and CNN can be performed for image segmentation, classification, and object detection. After detecting potholes, the route on Google Maps can be updated with pothole marks, and an alert can be sent to the users who select that route for travel. Image-based detection is more cost-effective than the 3D laser but more sensitive to environmental factors like rain, light, and shadow.

Vibration-based techniques acquire data from accelerometer and gyroscope sensors [1][11], which are present in smartphones, and work on changing the frequency principle while sensing vibration through embedded sensors in vehicles.

The collected data can be analyzed using ML and statistical approaches for pothole detection. With the help of a sensor, the change in the vehicle axis rotation can be processed, and potholes can be detected. After a pothole is detected, the processed data can be provided to intelligent vehicles deployed with AI technology to adjust their navigation and speed to prevent potholes. Similarly, an automated alert system integrated with an Android app can alert the users as well as relevant stakeholders before encountering a pothole within a permissible distance.

4.2 *Pothole detection using SSD*

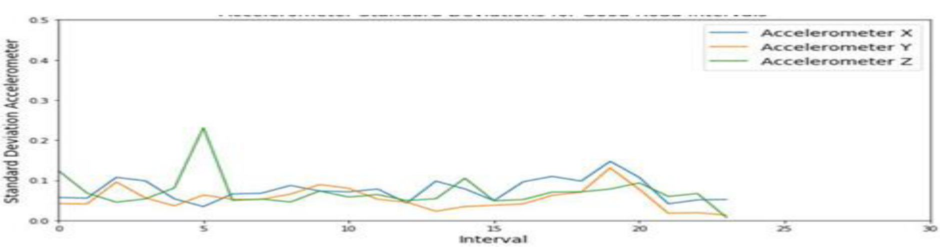
When a vehicle runs over a pothole, a gyroscope sensor captures the vibrations and uneven motions of the vehicle. An accelerometer detects acceleration in three dimensions (x, y, z) (Fig. 4).

While driving through an area with potholes, the accelerometer detects the vibration and saves the latitude and longitude of the pothole over a map. The smartphone can transfer the model to TensorFlow Lite for real-time pothole identification. TensorFlow object identification API includes trained deep learning models. TensorFlow is deployed to train the model on the custom dataset of potholes. The location coordinates are uploaded to the database as soon as the model determines that the reading is due to a pothole. The model was integrated into the Android application. The user interface of the application is demonstrated in Fig. 5.

On the map, these coordinates can be seen by other system users. GPS is used to capture the location and time in all weather conditions. When a user enters source and destination details in the app, GPS gives a route, and the application displays the segments that consist of potholes.

Figure 2. Sample images of potholes used for training

Figure 3. Pothole detection through SSD on a route with (a) 91% confidence interval and (b) 93.70% confidence interval



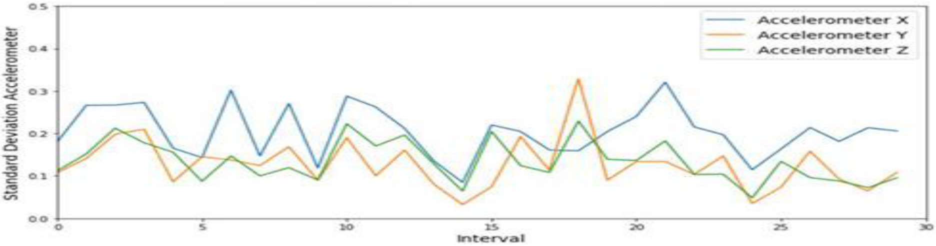


Figure 4. Accelerometer standard deviations (a) for smooth road intervals (b) for road with potholes

A route can be marked on the map whenever the user enters the source and destination location. After selecting the source and destination location in the application, the potholes on that route can be marked on the app, and the user can be notified before the pothole arrives. The app can email the municipal corporation an update on the pothole's location.

5. Discussions, Study implications and contributions

The proposed mind map (Fig. 1) contains integrational aspects of pothole detection like image-based detection, vibration-based detection, Road 4.0 technologies, Data modelling statistical methods, computational intelligence, analytical methods, road map integration, development of data centres, and data acquisition. The data can be acquired through camera images, an accelerometer, or a gyroscope. The image-based detection includes feature extraction, segmentation, smoothing, enhancement, classification, and algorithms for detecting potholes. In the vibration-based method, mobile sensors like accelerometers and gyroscopes can be used to detect the changes in vehicle axes for pothole detection.

With the help of image processing, relevant features can be extracted from the images provided (Fig. 1). The ease of data acquisition through smartphones can lead to fast and accurate ML-based models for pothole detection [1]. Vibration-based methods include an accelerometer for the characterization of road anomalies [9]. Sensors like accelerometers, electronic compasses, gyroscopes, cameras, GPS, etc., can be incorporated into mobile applications. Data processing and classification techniques like SVM, random forest, and logistics regression can be used for pothole detection. The mind map framework provides a detailed approach to developing an efficient pothole detection system.

In the proposed method, the SSD technique was used to train the pothole image dataset. The accelerometer detects the vibration and saves the latitude and longitude of the pothole over a map. The smartphone can transfer the model to TensorFlow Lite for real-time pothole identification. The location of potholes can be identified and validated by integrating Google Maps. After detecting potholes, the route on Google Maps can be updated with pothole marks, and an alert can be sent to the users who select that route for travel. When a user enters source and destination details in the app, GPS gives a route, and the application displays the segments that consist of potholes.

Using an integrated pothole detection application (Fig. 5), the vehicle will be able to collect data on the accurate location and condition of potholes. Besides, the proposed model would enable vehicles to send and receive alerts, giving time for drivers to slow down vehicles to avoid any mishaps and vehicle damage. The potholes marked on the map can help users know which route to select for a smooth ride.

Figure 5. (a) Flow chart of User Interface, (b) Potholes marked on the given route map and notification comes before the pothole arrives

The proposed model can assist municipal corporations in determining how this technology can gather road profile information, and data can be helpful in identifying and prioritizing pothole repairs. This research provides a detailed approach in terms of a mind map framework to illustrate how pothole detection can take place through different techniques. Users can check the number of potholes on the route and select an alternative route that is able to drive smoothly.

6. Conclusions, limitations, and future research

This research proposes a cost-efficient mobile app solution and a communication channel between stakeholders for pothole maintenance. The proposed mind map helps to understand the process of pothole detection in a comprehensive way. There is a potential to develop an integrated system that can be implemented on vehicles with smartphones, and it will beep when the phone camera identifies potholes on the road.

The dashboards of the automobile can be added to it to send an alarm on precise pothole areas. The pothole detection systems are generally dependent on machine learning algorithms. Integration of ML algorithms can be examined further. The applied SSD model for pothole detection makes more than 90% accuracy on small-scale data sets, however, due to small sample size, the model is difficult to apply in practice. The model can be made more accurate by increasing training data and by applying more different algorithms in future research.

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