Detection & Estimation of Potholes using Geospatial & Machine Intelligence

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Abstract—Road deterioration, characterized by issues such as potholes, cracks, and subgrade settlement, is on the rise due to weather fluctuations, including heavy rainfall and seasonal temperature variations attributed to global warming, as well as the use of conventional road construction techniques. This situation poses significant challenges for India. The traditional approaches to road surface management are becoming increasingly ineffective in light of the growing volume and condition of traffic on roadways, which continues to worsen daily. In India, there was a notable 50% increase in traffic accidents related to pothole issues in 2017 compared to previous years. Although numerous studies have been conducted on pothole repair, they often lack practical application. Therefore, it is essential to develop methods for the rapid detection of potholes with high accuracy and minimal cost.

Keywords—Potholes, Geo-tagging, QGIS.

INTRODUCTION

The construction of roads began many years ago, utilizing a variety of methods and materials. Over time, we have seen significant advancements and improvements in road construction techniques. Numerous studies are dedicated to enhancing the quality and durability of roads, aiming to ensure they remain resilient against issues such as cracks, subgrade settlement, and potholes. Nowadays, one of the fastest developed technologies and widely used in the mapping industry is using QGIS [1]. Urban areas are increasingly crowded due to the large influx of people moving into cities. Effectively managing such a population, with most individuals relocating from rural to urban areas. Pakistan is ranked as the top country in Asia for road accident fatalities In Pakistan, only four hundred cases were reported to RTA in Punjab; according to the "World Health Organization" report, 2.9% of deaths are caused by the RTAs [2]. When it comes to economic and social growth, one of the most essential things that a country may examine is its road quality. There is no country with a perfect road system; this is the reason why governments are required to implement measures to maintain roads within their respective areas. Road damage happens due to a range of factors, such as weather conditions, heavy traffic and inadequate selection of materials. This issue is expected to worsen as road maintenance becomes more frequent. Pavement Maintenance Management System (PMMS) involves comprehensive and organized activities designed in maintaining and managing asphalt pavements for inspiration. According to the information provided, the pavement management system generates a deterioration pattern for every sector and allocates the optimal strategy for maintaining something. Safety is maintained and ensures that all necessary precautions are taken [5].

A. RESEARCH METHODOLOGY

1) SELECT THE ROAD STRETCH: First select the road stretch lets say 1 km is selected for our study. In that 1 km length we need to identify the number of potholes and pictures of each pothole should be captured using smartphones or a camera with GPS feature turned on for the global positioning coordinates captured with photographs.

2) COLLECT POTHOLES DATA: The photographs were uploaded to QGIS software using the "import photo" plugin, which were further analyzed to get a visual map of selected terrain showing the photographs of potholes with their Latitudes & Longitudes, which shows the present condition of road pavement under the study area.

[1][4] There are several techniques available for pothole detection; however, most of them are labor-intensive and time-consuming. Conducting surveys over extensive areas poses significant challenges in terms of time constraints. QGIS software is employed for pothole detection, utilizing remote sensing and

GIS methodologies. In the case study, the identified potholes were geotagged using QGIS to create a location map. Initially, photographs were captured using a smartphone, ensuring that the GPS feature was activated and a measuring scale was placed next to the pothole for area calculations in AutoCAD. These images were then uploaded to QGIS through the "import photo" plugin, allowing for further analysis to generate a visual map of the selected area, displaying the potholes along with their latitude and longitude coordinates, which reflects the current condition of the road pavement in the study area[2]. The sensorial-based method is a technique that uses an accelerometer on a vehicle platform based for data collection. The advantages of this method are the small storage requirement, cost-effectiveness and feasibility for automatic real-time data processing. However, it does not provide detailed distress conditions of the road. The service condition of the vehicle also has a different impact on the result obtained from another vehicle; hence it needs constant vehicle parameters to make sure the data is comparable. Table 1 shows a previous study for the sensorial method [5][12].

Item	Vibration method	Vision based method/2D method	3D reconstruction
Equipment	Vibrator, gyroscope sensor, absorber sensor, mobile phone gyro	RGB camera, multispectral camera, satellite imagery	Stereo camera, RGB camera, laser scanner
Technique	Z-direction displacement	RGB image processing, multispectral classification	Stereo vision, photogrammetry, Light Detection and Ranging (LiDAR)
Platform	Car, van and mobile phone	Drone, car, van, satellite	Drone, car

Essential for pavement maintenance and management is having information on its condition. Therefore, there is a need for a uniform method to assess the condition of the pavement. Subsequent to the condition of a pavement can change, and a decision to conduct maintenance may be made as the most effective method to manage collected data in the field of geology suggested solutions for the problem. GIS is undeniably impressive, but it is not the primary focus method. Google Earth has the potential to display the information. While Google Earth and similar alternatives. While programs are beneficial, they do not possess the same level of strength as GIS. The data will be gathered through the traditional approach of visual examination by an individual person. Visual inspection data will serve as the main source of primary data for a thoroughly developed plan. Database utilized by GIS software. The additional data and information pertaining to the pavement and traffic. Permission will be acquired from the local authorities to serve as supporting data for the research. Google Earth is a virtual globe that allows users to explore the planet through satellite imagery, maps, 3D buildings, and other geographic information. Pro is utilized for accessing spatial data coordinates and locations. The study will begin with a preliminary investigation to identify problems and unfavorable strategies to promote a key point. At this point, the extent of what is considered reasonable is not completely defined yet a feasible plan. In every study, the purpose of research will be the goals of completion. The study will continue pursuing the goals until they are successfully achieved. The text will need to be provided in order to paraphrase it as requested. The ways in which goals are achieved will depend on the methods or strategies being implemented. Application of this concept is essential for success in our business operations. The research will depend on the strategy for completion. Gathering data is an essential step to achieve significant validations in research [6][10]. This section provides a detailed explanation of the main procedures and sources of information used in the suggested approach. They were employed in the method. In this particular investigation, the suggested model was trained using a dataset of images showing potholes. Super-resolution generative adversarial networks are used to enhance the visual quality of images by enlarging them. Increasing by a factor of four while simultaneously generating high-quality images from low-quality images. A VGG-16 CNN was utilized by us. A model that has been pre-trained on the ImageNet dataset to offer well-trained parameters for enhancing prediction accuracy. CNN model which was suggested. This enabled us to generate more precise outcomes (weights). In order to adequately train the CNN model, we must initially train the parameters and weights of the pre-trained models separately before applying those configurations to the CNN model. Due to this reason, we improved the predictive abilities of the recommended CNN model. Prior to being merged with the rest of the images, each shot undergoes data augmentation first, where they are zoomed horizontally, and the directions that are perpendicular to the horizontal plane. ReLu is used in all of the studies. Highlighting the importance of the soft-max function is crucial. The top prediction layer of the model was utilized to accurately depict the data. This point is worth noting. At this point in time, we will implement the VGG16 model into the Transfer Learning (TL) model that we have suggested. First, we remove the final three FC stages of the VGG-16 model. Following that, we substitute those layers with a fully connected CNN layer. This must be done in order to ensure that the output qualities will meet the binary classification standards. The data transmission managed by the established system for identifying and grouping potholes is illustrated [8]. Here we have used YOLO (you only look once) real time object detection system to detect the edges of the pothole in the given frame and mark a rectangular box. It divides the image into different grid cells. It has 2 fully connected layers along with 24 convolutional layers. Using different inbuilt function such as conv2D, batch normalization we enhanced the image, leaky relu is the activation function is in this neural network to add the linear properties.

The steps followed for the image detection is

1. Read the image using inbuilt function in the python 'input'
2. Create database split it into Train-Validation and Test by ratio 80-10-10
3. Train and validate the datasets using CNN using YOLOv2 real time object detection system
4. YOLOv2 Model has following layers

a) 2D convolutional layer which is implemented as conv2D

b) Batch normalization which includes standardization of input to layer for each mini batch

c) Activation function 'LeakyRelu' for adding non-linearity into model d) Discretized the image using max pooling2d which is sample based discretization process

5. Test it on images acquired by pi-camera interfaced in proposed system and calculate diameter of pothole to indicate intensity of pothole as shown in figure 6 A. and 6 B which indicates Test image of pothole and detected potholes after testing it

Training software (CNN): The software we have used here is for image processing, A Convolutional neural network (CNN) is a type of artificial neural network used in image recognition and processing that is specifically designed to process pixel data. The model which we used has been trained with 150 images which have 568 potholes labels. The accuracy of the model will increase by training the model with a larger size dataset. A neural network is a system of hardware and/or software patterned after the operation [9][13]. Figure 1 shows the system used for the study. As shown in Figure 1, the sensors were mounted on a portable rigid frame that can be mounted on a pick-up truck.

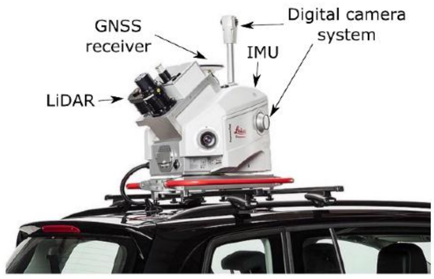

Fig 1: The data collection system.

The system comprised a LiDAR, global navigation satellite system (GNSS), and a camera. LiDAR was used to scan the pavement and obtain spatial information from the point cloud. LiDAR point clouds contain 3D geospatial information which can be used to obtain 3D geospatial information of pavement. The GNSS was used for georeferencing the location of the pothole detected from LiDAR point clouds. In this study, the LiDAR used was an OS-0 manufactured by Ouster®. The LiDAR has a 90◦ vertical field of view (FOV) covered by 128 rings. A GNSS system manufactured by Intertial Labs® was used for georeferencing. The sensors were connected to a laptop, which served as the control hub for operating and managing data collection and evaluation [7].

1. Site Reconnaissance and Planning: This phase includes selecting the study area (roads at UiTM Shah Alam and Seksyen 7), choosing equipment (like thread, tape, and ruler), and setting up camera calibration and software for data processing.
2. Data Acquisition: This phase combines conventional methods (measuring with tape and ruler) and UAV (drone) image capture to collect data on road conditions, including ruts and potholes.

3. Data Processing: The collected data is processed using software to align photos, build 3D models (dense cloud, mesh, tiled model, DEM, and orthomosaic). The road condition parameters (length, size of ruts, potholes) are measured from these models.
4. Results and Data Analysis: The measurements from UAV images are compared to field measurements to assess the accuracy. The analysis helps in evaluating the road conditions like potholes and ruts, which affect daily traffic.

The study uses a DJI Phantom 3 Professional UAV for aerial image capture. The camera is calibrated for accurate 3D modeling. Software like Map Pilot is used to plan the flight, and Agisoft Photoscan processes the images to create 3D models, while Global Mapper helps measure the size and depth of potholes and ruts. Results are validated by comparing with manual field measurements, with differences within 1 cm [11]. Many machine learning and deep learning techniques have been developed for detecting road cracks, and some have shown good performance. However, a common issue with these methods is that they are not trained on large and diverse datasets. Additionally, they often require significant time and computing power due to their complex designs with numerous parameters.

In this study, a decision-making system is introduced to identify road cracks and potholes. The training process uses a custom-built dataset of road images, captured using various devices to ensure diversity and effectiveness. [14] Potholes are a significant hazard to road safety and a drain on maintenance budgets. Existing detection systems are often ineffective. Our solution leverages advanced computer vision and real-time image processing to detect potholes using vehicle-mounted cameras. It integrates seamlessly with Google Maps for live pothole tracking and automates reporting via email alerts to relevant authorities.

This system enables precise mapping of pothole locations, helping drivers avoid unsafe routes and assisting road repair teams in prioritizing repairs. The streamlined reporting process ensures quick communication with authorities, accelerating repairs and reducing vehicle damage costs, such as tire and alignment issues.

Beyond safety, this technology reduces road maintenance costs, minimizes traffic disruptions, and enhances transportation efficiency. By using smart technology, our system creates safer, better-maintained roads and promotes a more cost-effective maintenance ecosystem [15]. For a real-time pothole detection system, each image in the dataset is manually annotated after collection. The annotated dataset is then divided into training and testing sets. These sets are used to train deep learning models, such as those in the YOLO family and SSD, to create a custom model.

The model's performance is evaluated on the testing data using the trained weights. These weights are then converted into the OpenVINO IR format, enabling real-time detection on devices like the OAK-D camera and Raspberry Pi, which act as the host computer. Further details of the methodology are provided in the next sections [16]. This project focuses on building an automated machine learning system for real-time road pothole detection and object detection. It identifies potholes, categorizes their severity, and detects animals on roads, aiming to enhance road safety, improve maintenance, and reduce wildlife collisions. The system is adaptable, user-friendly, and suitable for both urban and rural environments.

1. Pothole Detection: Utilizes Convolutional Neural Networks (CNNs), which are highly effective for image-related tasks like object detection, segmentation, and classification. CNNs excel at processing grid-like data such as photos, making them ideal for detecting potholes.
2. Object Detection: Employs YOLOv8, a fast and accurate real-time object detection model. YOLOv8 divides images into grids, predicting bounding boxes and class probabilities for each cell. It features an improved backbone architecture, CSPNet, for better performance. YOLOv8 offers multiple model sizes, from the compact Nano (fastest) to the larger YOLOv8x (most accurate), supporting detection, classification, and segmentation tasks via Python or a command-line interface.

This system effectively combines CNN and YOLOv8 to ensure speed, accuracy, and scalability[17]. Object detection in this system is performed using YOLOv8, a cutting-edge, fast, and accurate real-time object detection algorithm. YOLOv8 divides an image into a grid, predicting bounding boxes, class probabilities, and confidence scores for each cell. It is built on a deep convolutional neural network (CNN) with an improved backbone architecture, CSPNet, which enhances accuracy and efficiency. YOLOv8 is faster and more accurate than previous versions and supports tasks like object detection, classification, and segmentation. It provides a Python package and command-line interface for easy use and offers five model sizes, ranging from the compact and speedy YOLOv8 Nano to the highly accurate but slower YOLOv8x[18]. This study presents an integrated model for detecting traffic events and their locations, consisting of four main phases, as illustrated in Figure 1:

1.Collecting Real-Time Tweets: Utilizing the Twitter Streaming API to gather live tweets.

2.Tweet Preprocessing and Location Extraction: Cleaning the tweets and extracting location information.

3.Choosing Word Embeddings and Deep Learning Models: Selecting the appropriate word-embedding techniques and deep learning models for analysis.

4. Implementing and Evaluating Models: Applying the deep learning models to classify traffic-related events and assessing their performance [19]. The model is built using a custom dataset. The training dataset includes 3,178 pothole images sourced from the Roboflow online dataset and real-world images taken on a spur road of NH-44 (Hyderabad-Nizamabad-Nagpur section). These images showcase potholes of various shapes and sizes. For validation, 50 real-world pothole images were used, while 38 real-world pothole images were reserved for testing. Both validation and test images were captured using a downward-facing digital camera set at a height of 145 cm from the ground. Figure 2 illustrates some of the pothole images from the dataset.

Since the training dataset is relatively small, augmentation techniques such as vertical flips, horizontal flips, and 90-degree rotations were applied to the original training images to enhance model performance and prevent overfitting.

To annotate the images, the open-source tool LabelImg was used. The annotations were created in YOLO format, which includes the following parameters: [object class, X-center, Y-center, height, width] [20]. Deep learning object detectors are categorized into two-stage and one-stage detectors:

1. Two-Stage Detectors:

a. First, a Region Proposal Network (RPN) generates bounding box proposals that likely contain objects.
b. Then, features from these boxes are extracted using RoI pooling for classification and bounding box regression.
c. Example: Faster R-CNN, known for its high accuracy in object localization and recognition.

2.One-Stage Detectors:

a. Models like YOLO and SSD predict bounding boxes and classifications simultaneously, skipping the region proposal step.
b. These are faster than two-stage detectors and are widely used for real-time applications.

Backbone Network: Backbones extract features from images and produce feature maps used for detection and classification. Popular backbones like VGG16, ResNet50, and Darknet enhance accuracy by using deeper layers for feature extraction.

B. AREA CALCULATION:

There are various methods for calculating the area of a pothole like using MATLAB software and sensors like the Kinect sensor which uses infrared waves to calculate area and depth of the pothole instantly, but these methods are very expensive and require experts for handling. So, we are going to select area calculation using AutoCAD which is a relatively easy and inexpensive method but is time consuming. The area calculation for the pothole should be performed using AUTOCAD software. The pictures of potholes taken with measuring scale kept aside during the Geotagging of potholes and then imported in the AUTOCAD software using "IM" command, then the area for the captured pothole was calculated by plotting edge using "polyline" command and by scale referencing feature in AUTOCAD scale is adjusted and area is calculated using "area" command. And the area is recorded for further processing.

C. DEPTH CALCULATION:

Collection of data by using surveying instruments is too complicated. But using ODK, unskilled people can also handle it easily, and accurate results can be obtained. Climatic conditions don't affect the survey work when ODK is being used. And it also reduces the total cost of the project and requires less time for completion of the survey. Depth calculations should be done manually at each pothole by taking an average of 5 readings of depth at various points in the pothole and recorded the same in the ODK application which further gives the summarized data of all pothole depths collected in the study in required formats. We can calculate the volume of pothole i.e., volume of material required to fill pothole by following calculations:

Volume = Average depth of pothole × Area of pothole

Thus, by calculating the volume of all detected potholes we can get,

- Estimate of the total amount of filler material required for the repair of potholes.
- This estimate can optimize the filler material cost necessary for fixing the pothole.
- It saves the wastage material cost.

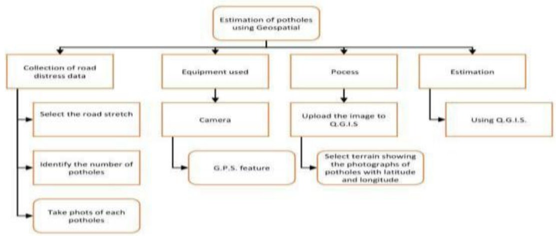

Fig.1. Flow chart for estimation of Potholes.

CONCLUSION

Heavy traffic and water accumulation on roads contribute to the formation of potholes. Research indicates that inadequate drainage systems and substandard mixing of construction aggregates are significant factors leading to pothole development, which can result in numerous fatalities. A considerable number of road accidents have been attributed to potholes. This study aims to develop a method for detecting potholes and assessing the amount of material needed for repairs. While there are advanced detection techniques that utilize expensive sensors and heavy machinery, this research seeks a more accessible and cost-effective solution that does not rely on such costly equipment. By adopting this approach, pothole detection and road maintenance can be simplified, ultimately reducing the risk of accidents caused by potholes and enhancing overall road quality.

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