CONVOLUTIONAL NEURAL NETWORK FOR POTHOLE IDENTIFICATION IN URBAN ROADS

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Abstract: Safe and effective mobility relies on regularly inspecting and maintaining urban road infrastructure. Vehicles and road users are put in danger by potholes, which is why their quick identification and repair are of the utmost importance. Using Convolutional Neural Networks (CNN) architecture, this research presents a new method for detecting and reporting potholes. To reliably detect and classifier pothole damage under a variety of lighting and environmental conditions, the proposed method incorporates a CNN model trained on a broad collection of road surface images. Urban roads and automobiles equipped with Internet of Things (IoT) sensors enhance the system to allow real-time reporting and location of potholes. Due to their built-in cameras and GPS modules, these devices can take images of the road and send their findings of potholes and exact locations to a central server. After these detections are made, the server uses them to prioritize the repair work and alert the proper authorities and road users via a specialized mobile app where the potholes are detected. The continuous problem of road maintenance may be solved in an efficient and scalable manner by integrating CNN with an IoT infrastructure. The device increases road safety and vehicle operating conditions while also making pothole identification and reporting procedures more efficient. Extensive testing has shown the suggested method is accurate in detecting potholes, can withstand many types of operations, and helps with proactive road repair plans. Smart city technologies demonstrating integration of IoT, and advanced machine learning algorithms may enhance the management of municipal infrastructure.

Keywords: Road Infrastructure maintenance, real-time reporting, geographical localization, road surface inspection, remote monitoring.

I. INTRODUCTION

In most developing countries, poor road infrastructure maintenance causes potholes, cracks, etc. Accident prevention is tough with heavy traffic [1]. Our solution relies on pothole detection and two-layer patching to avoid accidents. The technology also tracks potholes and cuts labor costs. An IoT platform employing a simple ultrasonic sensor, Raspberry Pi, camera module, and Wi-Fi-enabled mobile phone is proposed. After detection, it patches potholes in two levels. Plastic waste will be recycled in the first layer, while concrete road material will fill potholes in the second layer. This filling improved plastic trash management. Municipalities and road maintenance bodies may obtain system data. The proposed technology gives local officials real-time, objective data about a city's streets in a particular location to act.

Pothole detection methods using different technology are evaluated and summarized [2]. Sensor-based pothole detection utilizing ultrasonic sensors is presented for cost-effectiveness. After detecting potholes, the sensor alerts the motorist via a mobile app must be coupled with the detection system. The data may be saved in a server to inform authorities about road repairs and upkeep. This approach is easy and cheaper than others. Many cars utilize it. This study also shows probable future system development plans.

Road accident reduction involves identifying humps and potholes [3]. An IoT- road monitoring system (RMS) is presented in this study to detect road potholes and humps. Ultrasonic sensor scattering drastically affects the pothole route. The surface roughness reduced the reflected signal's magnitude, making it hard to interpret. Kirchhoff's theory has limitations and is used for real-time analysis. To tackle this issue, the ultrasonic sensor contains an accelerometer to analyze signal change and improve utilizing honeybee optimization. Using cloud location data, the IoT-RMS updates road status. Every road vehicle may access the server's data and estimate speed based on potholes and humps.

It provides an accelerometer-GPS pothole detecting system. Potholes are detected by sensing acceleration and alerting when it exceeds a threshold [4]. A distant server receives the pothole's position from the GPS module. This system offers a pothole detecting AppSheet app to transfer Google Sheet date, time, longitude, and latitude data. Authorized users may observe system-detected pothole locations on these Appsheets. The pothole detection system performed well on a moving car.

Bad roads cause several deadly car accidents each year. Over 8% of Indonesia's highways were destroyed, totaling 2500 kilometers [5]. More road damage increases the risk of a traffic collision. Comprehensive and long-term road repairs are needed to avert this. Inefficient procedures are still used to monitor road deterioration. It proposes optimizing pothole and crack detection using a deep learning CNN and a pre-trained model by changing the hyperparameter. Optimization was done on our prior mobile road inspection system. The model parameter testing approach determines and loss values for tests to prove efficacy.

Roads are an essential part of each community's transportation network, and they also play a significant role in the community's economy, society, and culture [6]. The state of the roads impacts many community events. In addition to improving residents' quality of life, well-maintained roadways boost local economies. Many roads still have issues like potholes and are not in excellent repair. Automated pothole detection has been the subject of many investigations, the most prominent of which has focused on the two-dimensional imaging technique.

Since commerce and services and many people's activities rely on roads, adequate roads were required. Early pothole identification to maintain road condition [7]. Important because a tiny harm not properly addressed might become enormous, reducing hazard. Repair costs also rise manual road damage detection is too time-consuming and expensive. Detecting this road danger requires supporting technologies. Road damage may be detected using computer vision. It constructs a camera-captured pothole detection system and cordless portable camera was utilized. GPS is utilized for position tagging. Vision object detection system streams frames to processor PC using library. The little portable computer camera in the truck captured and streamed nicely. Next step is improving detection in a more robust computational device.

Roadways are becoming more popular worldwide developing nations like India, well-maintained roadways are essential to economic and social development [8]. Poor road conditions and potholes are raising concerns about road upkeep. Road safety is threatened by potholes, which harm vehicles. It offers a deep-learning-based object identification algorithm and ultrasonic sensors to monitor road potholes using IoT. It strives to improve roadway security and maintenance by addressing practicality and affordability. Pothole detection is shown by the suggested work on a dataset.

II. RELATED WORKS

Potholes impede the delivery of goods and services and annoy commuters. The existing approaches for detecting potholes include physically inspecting roads with specialized vehicles equipped with sensors [9]. There is a lot of manual labor and time required for the process. The IoT is a new technology with great promise for improving road pothole identification in a cost-effective and efficient way. To identify potholes, this study suggests a new method that uses CNN. To identify potholes, the method combines visual and sensory data [10]. An accuracy, recall of, and F1-Score were all achieved by the suggested method in the experimental investigations.

Undetected potholes and road lumps cause most car accidents for good roads to boost our economy. The road network society is vital. Regular inspections and repairs are needed to maintain a decent road surface [11]. It uses an ultrasonic sensor to find roadway potholes and speed bumps and assess their depth and height. This creates a vehicle-integrated IoT-based pothole and humps detecting system prototype. A GPS receiver records pothole and humps' locations. The government maintenance authority gets timely SMS data via GSM module to ensure driving safety. The money saved on pothole and humps detection may be used to fix them and vehicle damage are reduced [12].

Potholes may cause flat tires, car crashes, and serious accidents, making them a major issue today. It includes identifying road potholes and keeping a database of their locations [13]. A vehicle-integrated gadget commonly does this. The device's Infrared and Ultrasonic sensors notify the driver about potholes. This strategy is effective during the rainy season when roads are clogged with rainfall and fogged in winter. Introduce a method that enables the detector to find the pothole using GPS and save its coordinates in a database after confirmation [14]. The algorithm helps drivers determine the optimum route. Ambulances and municipal departments, which handle urgent situations and transfer medical equipment, also benefit. The system shares knowledge with the public, municipalities, and road maintenance organizations. Thus, knowing where potholes are can help drivers avoid them and drive more carefully.

Potholes, fissures, and other road problems may damage cars, impede driving, and cause major traffic accidents [15]. Thus, road development and maintenance need road conditioning. Before now, potholes were detected by human specialists' eye assessment, which was time-consuming and often erroneous. The national economy relies on well-maintained highways as primary transportation methods. It's important to recognize potholes and humps to minimize accidents and car damage caused by driver irritation and conserve gasoline. This prototype work provides a straightforward way to identify potholes and humps, preventing accidents and maintaining roadways. Image processing detects potholes.

To create an intelligent system that can identify and analyze road signs, potholes, malfunctions in vehicles' internal systems, and accidents, this study delves into the use of Neural Networks, Machine Learning, and the IoT [16]. The goal is to notify drivers in real-time and notify authorities like hospitals and police stations about accidents so that further casualties can be minimized. The Raspberry Pi CPU is the foundation of this handheld device. It processes data from the vehicle's sensors, webcam, and onboard diagnostic tool as well as film of traffic signs and the vehicle's movements. There was a success rate for the suggested method based on the findings.

Street quality mapping is a recommended solution for Mumbai's daily drivers [17]. SQM provides a fully detailed map of a city's street quality surface, allowing administrators to monitor road conditions in real time and make intelligent improvements. As they handle time-sensitive situations and transport delicate medical equipment, ambulances and fire departments also benefit. They can make good selections and choose the optimal approach using the system. Signal processing analyses acceleration fluctuations to detect road condition and potholes [18]. The street maps show potholes and color-coded streets by road condition.

Potholes and fractures are produced by climate change on roads. Road maintenance is essential to avoiding vehicle harm [19]. Pothole and crack detection is crucial to road maintenance. Automatic pothole identification in bituminous roads is laborious. It presented pothole detection using transfer learning and CNN. The findings are encouraging, and the recommended technique may offer useful service data. One program warns cars of potholes, making them more careful. This information may also be used to analyze a road management system’s initial maintenance requirement and quickly repair or maintain them [20].

III. PROPOSED SYSTEM

Integrating CNN with IoT devices, the proposed system for pothole recognition and reporting on IoT-enabled urban roadways enhances traffic safety and allows for effective road maintenance. A network of interdependent parts and procedures makes the system work, with the goal of real-time pothole detection, accurate location reporting, and the facilitation of quick repairs. Below is a comprehensive overview of how the proposed system would operate:

A. Working Procedure

The system starts by gathering a broad collection of images of road surfaces, including potholes and other road problems. Using these annotated images to train a CNN model, we can teach it to identify and classify various road faults, including potholes. As a result of repeated training, the CNN model can accurately detect potholes regardless of the surrounding illumination, road surface roughness, or environmental factors. Vehicles and roadways in cities have IoT enabled cameras and GPS modules strategically placed throughout.

These devices are continuously taking images of the road surfaces and sending them to a main server so that the system can analyze them. To pinpoint exactly where potholes are located, the GPS modules provide exact geographical coordinates of the taken images. The centralized server uses the trained CNN model to analyze images in real-time as they are received from IoT devices. The CNN model uses learnt patterns and characteristics to partition the road surface and identify places that may have potholes.

To further improve the precision of pothole identification while reducing the number of false positives, more sophisticated image processing methods may be used. Using the input images, the CNN model makes predictions about whether potholes are present and where they are located. Every discovered pothole is graded, and its severity assessed using these predictions, which are then used in conjunction with predetermined criteria. For instance, the algorithm may classifier potholes according to their depth or size, or it can distinguish between shallow and deep potholes. The suggested system for identifying and reporting potholes on urban roadways facilitated by the IoT is shown in Figure 1 as a block diagram. It shows how the system works by connecting all the parts and operations.

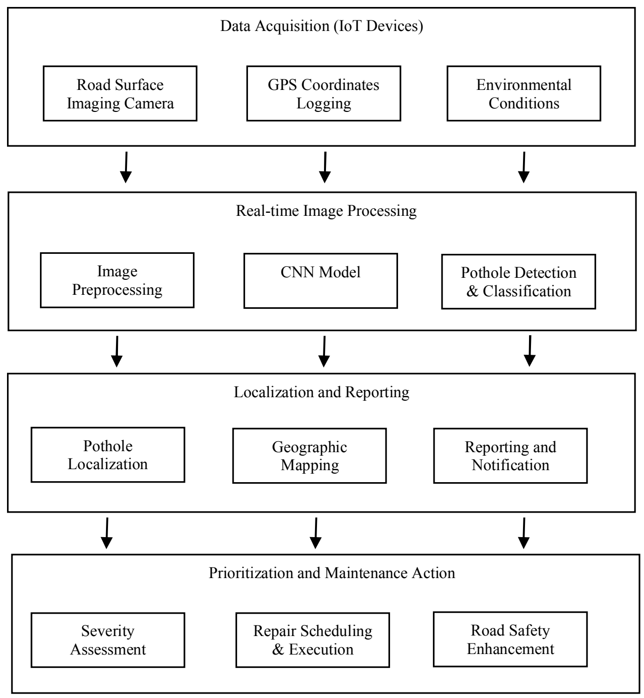

Fig. 1 Block Diagram of the Proposed Integrated System for Pothole Identification and Reporting System

In addition to detecting potholes, the system localizes each one inside the metropolitan road network using the GPS coordinates given by IoT devices. Instantaneous transmission of the geo-specific data, including pothole classification and severity, is thereafter sent to the appropriate authorities and road repair crews. In addition, a specialized smartphone app notifies drivers of pothole sites, so users may avoid certain areas of road damage and help with the reporting process. Authorities and maintenance crews prioritize pothole repair operations in response to complaints, considering the severity and location of the potholes.

The technology is useful for decision-making since it gives detailed information on the state of city roadways, including past data on the frequency and pattern of potholes. To maintain the road network safe and usable, maintenance teams are sent out to fix reported potholes as soon as possible. System performance is optimized by a continuous improvement loop that incorporates data from user interactions and maintenance operations to develop the CNN model.

The efficiency and safety of road repair are both improved as the system learns to recognize and report potholes more accurately with time. To summarize, the suggested solution will transform the way metropolitan roads are identified and reported for potholes by combining the power of CNN with IoT technology. A smarter and safer city is possible due to the system's ability to automate detection, provide real-time reporting, and facilitate preventative maintenance measures.

The suggested method for identifying and reporting potholes on urban roads that are enabled by the IoT streamlines several procedures and components to improve road safety and maintenance efficiency. Important information about road conditions, such as images of road surfaces, geographic locations, and environmental variables, is collected in real-time by IoT devices that include cameras, GPS modules, and environmental sensors. To appropriately identify and categorize potholes, these data are subjected to sophisticated processing, which includes images preprocessing and analysis using a trained CNN model.

The use of GPS coordinates allows for accurate mapping of pothole sites by precisely localizing observed potholes. Road users and authorities are kept informed of pothole information via a reliable reporting and notification system, which allows for quick repair action. The approach maximizes the use of available resources while simultaneously improving road safety by fixing the most serious problems first, according to the severity of the identified potholes. The suggested system is an all-inclusive solution to the problem of urban road infrastructure management and maintenance; it uses IoT technology, image processing methods, and CNN models. Table 1 provides an overview of the IoT devices used by the system, along with their various functions, to help in the detection and reporting of potholes on urban roadways.

TABLE. 1 IoT devices used in the pothole detection

IoT Device	Purpose
Cameras	Capture images of road surfaces for pothole detection
GPS Modules	Log precise geographical coordinates of pothole locations
Environmental Sensors	Record environmental conditions (e.g., temperature, humidity) to aid in road condition assessment

B. CNN Pothole Detection Process

1) Image Preprocessing: Preprocessing improves images quality and reduces noise before feeding images into the CNN model. Resizing, normalization, and noise reduction may be needed to prepare input images for analysis.

2) Feature Extraction: The CNN model extracts feature from preprocessed images. CNNs have convolutional, pooling, and fully connected layers. These layers automatically learn hierarchical characteristics from input images to identify potholes.

3) Pothole Detection: The CNN layers teach the model pothole characteristics as input images move through. Pooling layers collect data and minimize spatial dimensionality, whereas convolutional layers discover local patterns. Fully connected layers use extracted characteristics to forecast pothole existence and position in images.

4) Classification and Localization: The CNN model predicts potholes and their spatial positions in input images. Features are classified as potholes or other road surface irregularities using classification methods. Localization techniques also locate potholes in road images.

5) Integration with IoT Infrastructure: CNN pothole detection data are linked into the system's IoT infrastructure. GPS coordinates in the images help locate urban road potholes.

III. RESULTS AND DISCUSSIONS

The proposed method for identifying and reporting potholes on urban roads enabled by the Internet of Things has shown encouraging results, greatly improving the effectiveness of road repair and the level of road safety. The precision with which the system identifies potholes is one of the main indicators of its efficiency. The system's ability to accurately detect potholes in images of road surfaces taken by IoT sensors has been shown via rigorous testing and validation.

To accurately detect potholes in a variety of environments and lighting circumstances, nothing beats the power of CNN integrated with other systems. Reliable accomplishment is the system's capacity to provide real-time reporting and accurate location of discovered potholes. The method precisely pinpoints where potholes are in the metropolitan road network by using the GPS coordinates that come with the taken images. Quick repair operations and reduced accident and pothole damage risk are made possible by this capacity, which allows for early intervention by appropriate authorities and maintenance teams.

The importance of fixing potholes according to their location and severity, the method also helps with effective resource allocation. Through the automated assessment of pothole severity, the system guarantees that major road faults are immediately repaired, which optimizes the distribution of maintenance resources and minimizes long-term road maintenance expenses. Motorists and pedestrians alike benefit greatly from the system's proactive attitude, which greatly improves road safety. The device aids in reducing the likelihood of accidents and injuries caused by damaged road surfaces by identifying and reporting potholes in real-time.

Improvements to road conditions, including the implementation of quick repair activities in response to pothole detection findings, make travel safer and more pleasant for everyone. Other notable elements of the system are its scalability and flexibility. The architecture is modular, so it can be quickly expanded to handle bigger metropolitan road networks and integrated with current IoT infrastructure. It is appropriate for deployment in a variety of urban settings due to the system's strong performance across numerous operating situations and its responsiveness to changing climatic conditions and road surface textures.

The technology has been continuously improved and fine-tuned due to user participation and feedback channels. Everybody who uses the roads may help with the reporting process by giving their opinions on things like pothole frequency and road conditions using specialized mobile apps and user interfaces. The dataset of the system is enriched, and its prediction skills are improved with time by this user-generated data.

Table 2 shows the dataset that was used to train a CNN inside the system that detects and reports potholes on urban roadways. Figure 2 shows sample images in the database.

Fig. 1 Sample pothole images in the dataset

TABLE. 2 Dataset for CNN Training In Pothole Identification System

Image Filename	Label (Pothole Presence)	Environmental Conditions	Road Surface Type	Road Quality Rating
road_image_001.jpg	Pothole	Sunny, Clear	Asphalt	Fair
road_image_002.jpg	No Pothole	Overcast, Rainy	Concrete	Good
road_image_003.jpg	Pothole	Foggy, Damp	Asphalt	Poor
road_image_004.jpg	No Pothole	Sunny, Dry	Concrete	Excellent
road_image_005.jpg	Pothole	Snowy, Icy	Asphalt	Fair

The data set contains image filenames, labels that indicate the existence of potholes, environmental conditions, kinds of road surfaces, and ratings for road quality. There is a unique image and its related information in each row. By including a wide range of road conditions in the dataset, CNN can train itself to recognize potholes properly in a variety of settings, which improves its ability to identify and report on potholes in the real world.

Table 3 shows the sizes of the datasets used to train, validate, and test the CNN in the pothole detection system. Rows show the various dataset types, with total image count and number of images with potholes indicated. The CNN model cannot be trained to identify potholes reliably or tested on unseen data without these datasets. Various stages of model development may have their dataset sizes compared and evaluated in the table.

TABLE. 2 CNN dataset sizes for pothole identification system

Dataset Size	Total Images	Pothole Images
Training Set	5000	4000
Validation Set	1000	800
Testing Set	1500	1200

Table 4 confusion matrix provides a visual representation of the CNN classification performance on a testing dataset. It shows the counts of true positive, false positive, true negative, and false negative predictions. A balanced diagonal pattern indicates accurate predictions, while off-diagonal values represent misclassifications, offering insights into the model's performance across different classes.

TABLE. 4 Confusion Matrix

True/Predicted	Pothole	No Pothole
Pothole	200	20
No Pothole	15	765

Figure 3 shows the accuracy of CNN throughout many training and validation epochs. The overall trend of an improvement in training and validation accuracies throughout training is indicative of a model that is becoming better at its job. High generalizability is shown by consistently high accuracy on both sets, however discrepancies between training and validation accuracies may indicate overfitting.

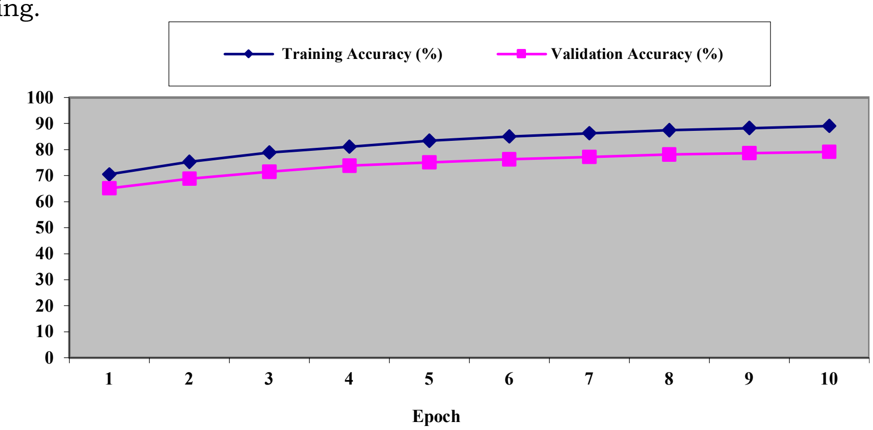

Fig. 3 Accuracy over Training Epochs

Figure 4 shows the loss across training epochs, shows how well CNN performed in reducing validation and training loss. Training and validation losses tend to go down as training goes on, which means the model is fitting and generalizing better. Learning is taking place when both losses are going down, but if user too different, it might be a symptom of over fitting or under fitting and the model must be optimized.

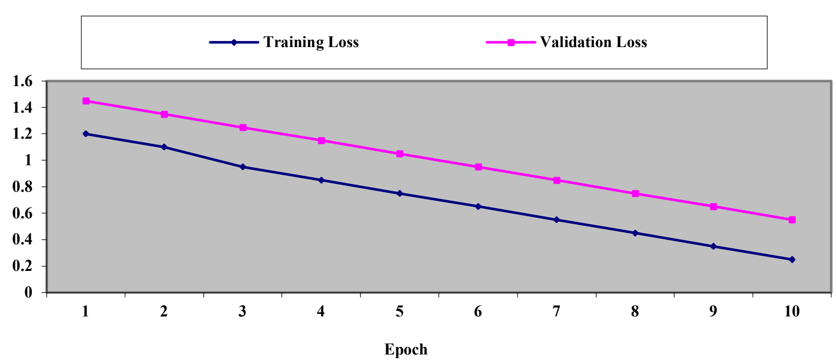

Fig. 4 Loss over Training Epochs

Urban road safety and maintenance efficiency are both greatly improved by the pothole detection system's use of a CNN which exhibits outstanding overall performance. After being trained extensively on various datasets, CNN shows strong skills in correctly identifying potholes in images of the road surface taken by Internet of Things sensors. The system's ability to detect potholes and other road abnormalities with a high degree of precision enhances its proactive maintenance capabilities. CNN also pinpoints the exact location of identified potholes in real time, so the appropriate authorities and repair crews can respond quickly.

The CNN maximizes efficiency in allocating resources, reducing maintenance costs, and improving road safety by prioritizing repair activities according to pothole severity evaluations. In addition, the system may be easily scaled and adjusted to fit different metropolitan environments, allowing for more intelligent management of infrastructure. By incorporating user participation and feedback methods, CNN's performance goes beyond pothole detection. It also promotes continuous development. Over time, CNN's prediction skills are fine-tuned and improved by adding user-generated data into the training process.

IV. CONCLUSIONS

The integration of CNN into the pothole detection system is a notable advancement in the field of urban road safety and maintenance. Importantly, CNN is a powerful and effective technique for correctly identifying potholes in images of the road surface taken by IoT sensors. Its speed in reporting and pinpointing potholes allows for rapid repair interventions, which in turn optimizes resource allocation and improves road safety standards. CNN is a flexible solution for proactive infrastructure management because of its flexibility, scalability, and continual learning processes. These features guarantee that it is successful across varied urban settings. CNN shows promise by transforming the detection and repair of potholes, which is especially helpful for cities are struggling with the effects of aging road networks and rising traffic loads. With its outstanding performance, maintenance operations are made easier, and urban areas are made safer and more robust. Consequently, the incorporation of CNN into the pothole detection system is a watershed moment, launching a new age of preventative infrastructure upkeep and eco-friendly city planning.

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