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Design and Implementation of Water Backflow Prevention and Pothole Detection in Subway

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Abstract: The proposed system is an integrated IoT-based solution that not only manages excess rainwater but also enhances road safety through intelligent pothole detection. Utilizing advanced moisture sensors, the system continuously monitors water levels and activates suction motors to promptly remove standing water during heavy rainfall. Servo motors further safeguard the environment by automatically blocking road access when critical water levels are detected, preventing vehicular damage and ensuring community safety. In addition, an ESP32-based module equipped with a Convolutional Neural Network (CNN) enables real-time pothole detection, allowing for early identification of road surface anomalies and facilitating timely maintenance. This dual-function approach leverages real-time data and automated responses to mitigate flood impacts and improve infrastructure resilience, thereby fostering a safer and more responsive urban environment.

[1] Introduction

Urban flooding and road infrastructure damage due to heavy rainfall pose significant challenges to public safety and transportation efficiency. The proposed IoT-based "Rainwater Removal and Pothole Detection System" addresses these issues by integrating automated water drainage and real-time pothole identification. By leveraging moisture sensors, suction motors, servo motors, and an ESP32-based CNN model, the system effectively manages excess rainwater while simultaneously detecting potholes to ensure safer roads. This smart infrastructure solution enhances disaster preparedness, reduces vehicular damage, and aids in maintaining urban road networks, making it a crucial innovation for modern city management.

1.1. General Introduction

Rapid urbanization and unpredictable weather patterns have intensified challenges related to urban flooding and road surface degradation. Excess rainwater accumulation on roads not only increases the risk of vehicular accidents but also accelerates pothole formation, further compromising road safety. Conventional drainage systems and manual pothole detection methods often prove inadequate in addressing these issues effectively.

To overcome these challenges, we propose an integrated IoT-based system that combines intelligent water management with real-time pothole detection. By leveraging advanced sensors, automation, and machine learning, the system enhances urban resilience against flooding while improving road safety. This dual-function approach ensures proactive flood mitigation and timely road maintenance, fostering a smarter and safer urban environment.

1.3. Problem Statement

Urban flooding and poor road conditions pose serious safety risks, leading to accidents and infrastructure damage. Excess rainwater causes waterlogging, while undetected potholes worsen over time, increasing maintenance costs and endangering commuters. Traditional drainage and inspection methods are slow and inefficient, lacking real-time intervention.

An integrated IoT-based system is needed to manage rainwater efficiently and enhance road safety through automated pothole detection. By enabling real-time monitoring and proactive response, this solution improves infrastructure resilience and ensures safer urban mobility

[2] Literature Survey

Pothole detection and inter vehicular communication

This paper aims at proposing a novel pothole detection system, which assists the driver to avoid potholes on the roads by giving prior warnings. The idea is to build a robot vehicle that is capable of detecting the potholes and transferring this information to the nearby vehicles in the vicinity. By sharing the information about potholes with the nearby vehicles, the probability of accidents or collision can be reduced. Here, we propose a pothole detection model, which can detect the potholes with a minimum depth of 1 inch and share the information within 100 m range. The application illustrated in this work can be effectively used to reduce the problem of increasing accidents caused due to potholes.",

Feedback Control and Monitoring System for a Potable Rainwater and Ground water Harvester.

"Feedback Control and Monitoring System for a Potable Rainwater and Groundwater Harvester aims to develop a device that will be able to measure the parameters of water that has passed through its filtration system. The system has a container for the output of the filter where parameters for potable drinking water are tested if standards for Class AA or potable water are met. For instance, a study by Marion D et al. (2018) If the water fails to meet the standards, the water from the container will be recirculated to the filter until it attains the standards. If the set standards are met, the water will be transferred to the final container and is ready for harvesting. The researchers gathered 30 trials for each water input such as rainwater and groundwater. For each trial, final readings of the parameters of the water that passed the standards are recorded. The data between the input and output of the system will be compared using t-test to determine if there is a significant change that is within the acceptable range of standards. The water results will be validated further by testing the water output in a laboratory that is certified by the International Organization for Standardization (ISO). The output will be then compared again to the output of the laboratory test to ensure water quality"

Rainfall monitoring using acoustic sensors

This study is about the design, development, and field testing of acoustic sensors for rain measurements. An Android-based acoustic sensor is designed and tested. xWe report, for the first time, the performance of an acoustic rain sensor and a tipping bucket in the same device. integrated with an Android phone. integrated with an Android phone. This new configuration shows the difference between a real-time acoustic rain sensor and a tipping bucket, which is an accumulation sensor. The analysis features and performance of the acoustic sensors directs to the development of low-cost devices for gathering rain data, which can supplement standard rain measurement devices".

Detection and Classification of Potholes in Indian Roads Using Wavelet Based Energy Modules

Maintenance of roads is one of the major challenges in developed countries. The well maintained roads always indicates the economy of the whole country. The heavy use of roads, environmental conditions and maintenance is not performed regularly that leads the formation of potholes which causes the accidents and unwanted traffics. The paper discuss about the detection of potholes based on wavelet energy field. The proposed method mainly includes three phases (A)Wavelet energy filed is constructed in order to detect the image by using geometric criteria and morphological processing (B)Extracting Region of intersect by edge based segmentation technique (C)Classifying the potholes using Neural Networks

A Modern Pothole Detection technique using Deep Learning

Road accident detection and avoidance are a more difficult and challenging problem in India as poor quality of construction materials get used in road drainage system construction. Due to the above problems, roads get damaged early and potholes appear on the roads which cause accidents. According to a report submitted by the Ministry of Road Transport and Highways transport research wing New Delhi in 2017, approximately 4,64,910 accidents happen per year in India. This paper proposed a deep learning-based model that can detect potholes early using images and videos which can reduce the chances of an accident. This model is basically based on Transfer Learning, Faster Region-based Convolutional Neural Network(F-RCNN) and Inception-V2. There are many models for pothole detection that uses the accelerometer (without using images and videos) with machine learning techniques, but a less number of pothole detection models can be found which uses only machine learning techniques to detect potholes. The results of this work have shown that our proposed model outperforms other existing techniques of potholes detection.

3. Existing Methodology

Traditional rainwater management systems rely on manually operated drainage mechanisms or static pumps, which often fail to respond effectively to sudden heavy rainfall. These systems lack automation and real-time monitoring, leading to delayed water removal, increased flood risks, and potential damage to infrastructure and vehicles. Similarly, pothole detection is primarily conducted through manual inspections or citizen reports, which are time-consuming, labor-intensive, and prone to errors. This delay in road maintenance increases the likelihood of accidents and vehicle damage, making the current approach inefficient and reactive rather than proactive.

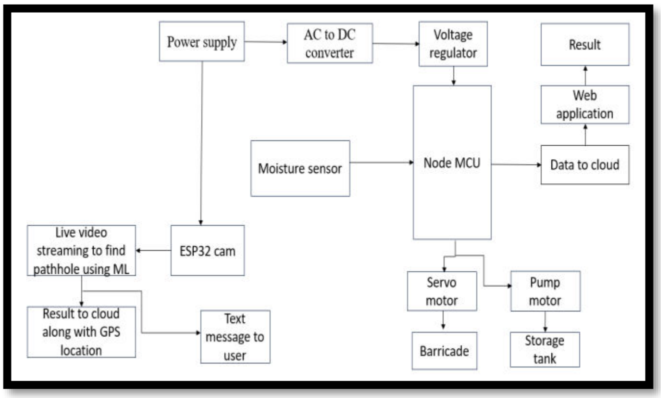
4. Proposed Methodology

The proposed IoT-based solution automates both rainwater removal and pothole detection using real-time monitoring and AI-driven analysis. Moisture sensors detect excess water levels and activate suction motors to drain accumulated rainwater efficiently, while servo motors automatically deploy road barriers to prevent vehicles from entering flooded areas. Simultaneously, an ESP32-CAM, integrated with a CNN-based image processing model, captures road conditions and identifies potholes with high accuracy. By leveraging IoT for data collection and AI for analysis, the system ensures proactive flood management and road maintenance, enhancing infrastructure resilience and public safety.

4.1 Working

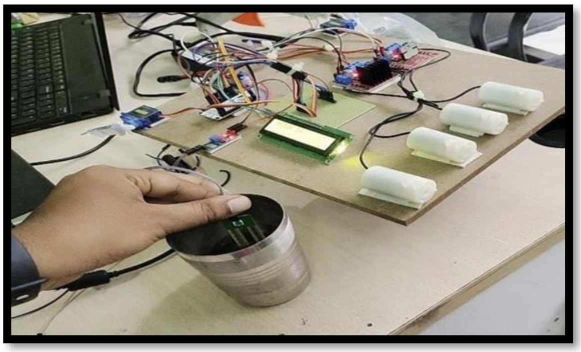
The rainwater removal system operates by continuously monitoring moisture levels using sensors placed at flood-prone areas. When water levels exceed the threshold, suction motors activate to drain the excess water, preventing accumulation. Simultaneously, servo motors deploy road barriers to restrict traffic flow in hazardous areas. For pothole detection, an ESP32 camera module captures road images, which are processed using a CNN model trained to identify potholes based on texture variations. The system then sends real-time notifications to relevant authorities for necessary repairs. By combining IoT and AI, this solution ensures efficient water management and improved road safety, making urban environments more resilient to extreme weather conditions.

4.2 Block Diagram

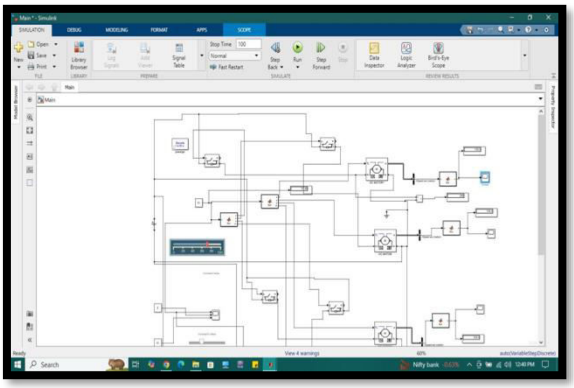


5. Result and Discussion

Hardware and Simulink Result

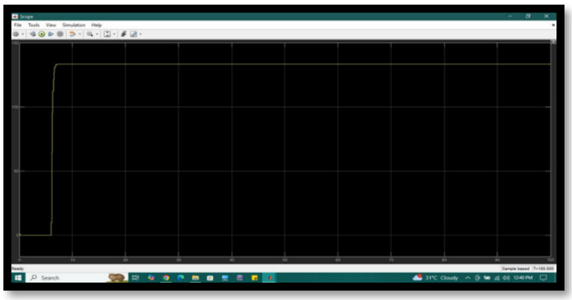


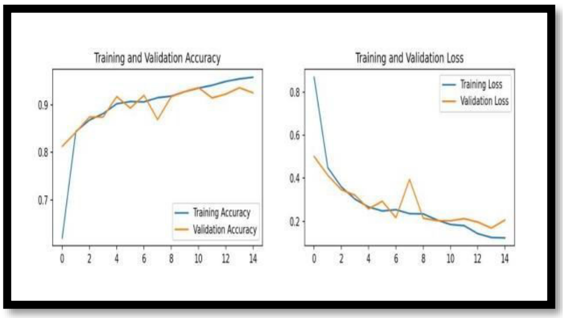
A water backflow prevention device managesflooding using key components. It features a NodeMCU Microcontroller for remote monitoring and control via Wi-Fi. Moisture Sensors detect water levels, sending alerts to the Node MCU when thresholds are exceeded. The device also includes H-Bridge Motor Drivers, Suction Motors, and Servo Motors to pump out water and manage barriers. These components work together to prevent flooding and restrict vehicle access to affected areas.



A flood control system utilizes various components to ensure public safety. These include Servo Motors for precise barrier control, DC motors and Pump motors for water removal, and Moisture sensors to monitor water levels. Additionally, TDS and

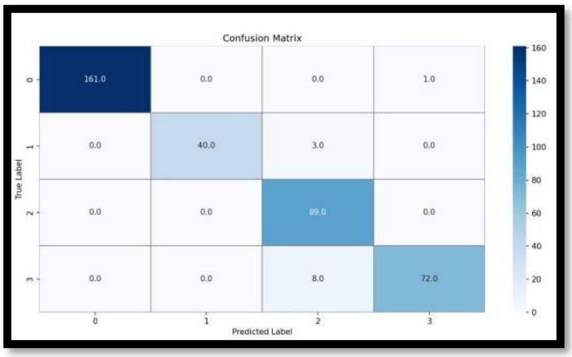
Turbidity sensors measure water quality, while Relays, Switches, and Scopes facilitate system monitoring and control. The system automatically activates pumps and controls barriers to prevent flooding and enhance public safety.





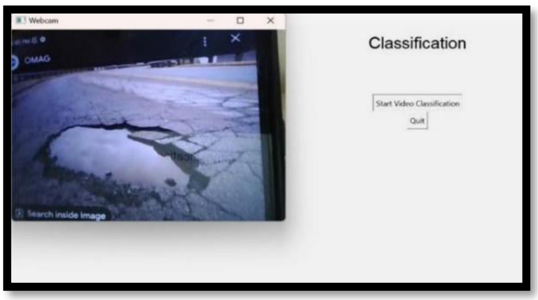
Graph Analysis

Graph analysis in pothole detection uses visualization to assess model performance. Key graphs include the Confusion Matrix Heatmap, Precision-Recall Curve, and ROC Curve, which evaluate classification performance and model effectiveness. The Loss vs. Epoch Curve tracks the model's error decrease over training iterations. The Accuracy vs. Epoch Curve displays accuracy improvement over training epochs. These graphs provide valuable insights into the model's strengths and weaknesses.



Confusion Matrix

A confusion matrix for pothole detection evaluates a model's performance in identifying potholes. It displays four key values: True Positives (TP), False Positives (FP), False Negatives (FN), and True Negatives (TN). These values measure accuracy, precision, recall, and overall performance. The matrix helps identify areas for improvement in the pothole detection system. Analyzing these values enables evaluation of the model's effectiveness.



Two Virtual Terminals are connected, allowing data to be transmitted between them. To simulate serial communication, the Arduino's Rx pin is connected to the Virtual Terminal's Tx pin, and vice versa. The HEX file is attached to the Arduino by double-clicking on it. After hitting the simulation button, the data sent by the Arduino is displayed in the Terminal window. This demonstrates successful serial communication over UART.

6. Conclusion

It was found that the method works relatively well discarding other vehicles although further search be performed to improve this aspect. By measuring the time it takes to perform the algorithms, it was found that the algorithm execution speed is adequate given a vehicle speed of less than 60 km/h although the actual maximum distance at which the pothole can be detected needs to be improved to account for the driver reaction time. The algorithm is successful in the detection of potholes and an attempt will be made to upgrade it to include potholes with no visible edges (due to sand or dirt) in future research. In a single model there will be a development of the traffic signal detection, lane detection and all the detections will be done in a very single model. For security purposes they are going to create protective barriers, it is going to increase the potential vulnerabilities, the usage of the bandwidth is going to be very efficient. They are going to provide a specialization and abstraction. There is going to be a one layer that misses the security, deployment and prototyping link between all the devices

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