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Advanced AI Framework for Urban Safety through Manhole Inspection and Maintenance

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Abstract

Manholes, essential components of urban utility infrastructure, provide access to underground systems like sewers, electrical conduits, and storm drains. However, deteriorated, open, or missing manhole covers pose significant hazards to pedestrians, cyclists, and vehicles, often leading to severe accidents. Traditional inspection methods rely on manual observation, which is labour-intensive, error-prone, and inefficient, particularly in large urban areas. Moreover, the increasing frequency of manhole-related incidents highlights the urgent need for an automated and reliable solution to ensure public safety and efficient maintenance of urban infrastructure. This project addresses these challenges by proposing an advanced deep learning based automated inspection system. The system utilizes Convolutional Neural Networks (CNN) for image classification and You Only Look Once version 8 (YOLOv8) for accurate detection and localization. It is trained on a diverse dataset to classify manhole covers into distinct categories, including 'Closed,' 'Open,' 'Broken,' 'Overflow,' and 'No Manhole.' The integration of UAV images and CCTV footage ensures comprehensive monitoring, even in hard-to-access areas or dynamic environments. By overcoming issues like variable image quality and complex backgrounds, this solution offers precise and timely identification of hazardous conditions. The implementation of this system presents a transformative approach to urban safety and maintenance. By automating the inspection process, it reduces reliance on manual labour, minimizes errors, and ensures timely intervention to address potential risks. This project not only enhances public safety but also optimizes resource allocation for infrastructure maintenance, offering a scalable and efficient solution to modern urban challenges.

Keywords: Manhole inspection, Urban infrastructure, public safety, Deep learning, CNN, YOLOv8, Image classification, Object detection, UAV and CCTV imagery, Automated monitoring, Infrastructure maintenance

1. Introduction

A manhole or an inspection chamber is a unit constructed underground to provide access to the utilities like a sewer system, drainage system, etc. Hence, with the help of a manhole, underground utilities are inspected, modified, cleaned and maintained. Sewer systems are built underground with pipes that carry waste from homes and other buildings to a place of treatment or disposal. Part of maintaining a sewer system is providing frequent inspection, cleaning and repairs. Utility crews use manholes to gain closer access to pipes or other parts of the underground system to meet those needs.

Manholes are built primarily for trenchless restoration of the sewer system, drainage system inspection, cleaning of clogged lines, and maintenance purposes. Manholes are also used as a first step for accessing the inside of a sewer line to help diagnose any issues with it and facilitate the replacement of damaged pipes without the need for digging. Up until the end of the main sewer line or drainage point, manholes are positioned throughout the sewer line. There are usually manholes located at several intervals down the drainage system to allow for maximum access. If one area is clear yet another is blocked, the manhole closest to the issue can be lifted and inspected, and any necessary work such as high-pressure water jetting can be carried out to clear the problem. If the water is flowing in along the pipe and then stops or backs up, the location of the problem can be confirmed by lifting the manholes and monitoring the water

levels. If the levels are high, it suggested there is a problem nearby which requires attention. The manhole covers are composed of metal, precast and composite material and come in a variety of sizes, materials, and designs, including rectangular, circular, and square. If the depth of the manhole chamber exceeds 2.5 m, a ladder must be installed inside; if the depth is little than 1 m, a step ladder is required.

There are three different types of manholes: shallow, normal and deep. “Normal” manholes are typically 4- to 5-feet deep and wide enough for the average person to fit in. "Shallow" manholes are 2- to 3-feet deep, often placed at the start of a sewer branch and in areas with low traffic. Manholes with a depth greater than 5-feet are considered "deep" and usually have an entry method like a ladder built-in, as well as a heavier cover. Manholes are designed with a cover or lid and comprised of grade adjusting rings, a top tapered section called the cone, a main cylinder section called the wall or barrel, and a bench and channel where the waste flows through.

Types of Manholes

The three main types of manholes depending on the depth are

- **Shallow Manhole:** A shallow manhole has a depth ranging between 75 to 90 cm. These are constructed at the start of a branch sewer or in an area where there is not much traffic. The shallow manhole is provided with a light cover called as the inspection chamber.
- **Normal Manhole:** These are provided at the sewer line with a heavy cover on its top. It has a depth of 150cm. Normal manhole takes a square shape.
- **Deep Manhole:** Deep manhole is provided at a depth greater than 150cm with a very heavy cover at its top. The size can be increased and the facility for going down is also increased.

2. Literature Review

The literature indicates remarkable progress in the automation of manhole detection and monitoring to improve urban safety and infrastructure management. Om Khare *et al*. (2023) [1] applied YOLOv8 for real-time road hazard detection, including potholes and manholes, with high accuracy in challenging urban environments. Apurva Kumari *et al*. (2023) [2] suggested a vision and sensor-based system to help visually impaired people detect manholes, improving their navigation safety. Ravi M. *et al*. (2023) [3] proposed an IoT system for manhole status monitoring via sensors to offer real-time maintenance alerts. Yue Liang *et al*. (2022) [4] proposed an intelligent management system with sensors and predictive analytics to streamline maintenance schedules and avoid failures. Xiaolin Zhang *et al*. (2022) [5] targeted visual inspection technologies for precision assembly of manhole covers in high-risk environments such as rocket fuel tanks.

Kriti Thakur *et al*. (2021) [6] integrated image processing and data analysis to develop an efficient manhole management system. Habib Shahorier Tasin *et al*. (2021) [7] managed the threat posed by uncapped manholes under waterlogged circumstances by creating an imaging technology-based detection system. Liyuan Qing *et al*. (2020) [8] developed a deep learning technique for computer-aided detection of manholes in MLS point clouds for massive-scale urban infrastructure mapping.

Uroš Andrijašević *et al*. (2020) [9] utilized RNNs to identify openings in manhole lids for ensuring no unauthorized entry and accidents. Finally, Vinay Vishnani *et al*. (2020) [10] implemented image processing on Google Street View images to make manhole detection and mapping automated in urban landscapes. These papers cumulatively highlight the success of smart systems in transforming manhole inspection and maintenance.

3. Problem Definition

Manholes present several significant challenges. Firstly, they pose safety hazards to pedestrians, cyclists, and motorists if left uncovered or improperly maintained, leading to accidents and injuries. Additionally, uncapped or poorly maintained manholes can become breeding grounds for pests and bacteria, raising public health concerns. Infrastructure damage is another issue, as damaged or corroded manholes can result in collapsed road surfaces or sewer lines, necessitating costly repairs.

Moreover, clogged or blocked manholes can cause flooding and drainage problems, resulting in property damage and environmental pollution. Accessibility challenges arise for individuals with disabilities when manholes lack proper accommodations, hindering their ability to navigate public spaces safely. Furthermore, open or unsecured manholes present security risks by providing unauthorized access to underground infrastructure, leading to vandalism and theft. Lastly, the maintenance burden of manholes is substantial, requiring regular inspection, cleaning, and upkeep, which can strain municipal resources.

Addressing these challenges requires proactive measures such as regular maintenance, infrastructure upgrades, public awareness campaigns, and improved design and security measures. The problem statement of the project revolves around addressing the multitude of challenges associated with manholes, particularly in urban environments. Manholes, while crucial for utility access and maintenance, present significant safety hazards, public health concerns, infrastructure damage, and accessibility issues if left unattended or improperly maintained. The lack of proper management and maintenance can lead to accidents, injuries, property damage, environmental pollution, and hindered mobility for individuals with disabilities. Additionally, the security risks posed by open or unsecured manholes further exacerbate the problem.

Therefore, the project aims to develop innovative solutions and technologies to enhance the detection, management, and maintenance of manholes, ensuring public safety, health, infrastructure resilience, and accessibility in urban areas.

4. Proposed System

The proposed system of the project is a web-based efficient manhole maintenance system that uses deep learning algorithms to classify manhole images into four categories: close, open, broken, or no manhole. The system comprises several steps, as follows:

1. **Dataset Collection:** A dataset of manhole images is collected from various sources, including Google Street View and local authorities.
2. **Pre-processing:** The images are pre-processed by converting them from RGB to grayscale, resizing them

to a uniform size, and applying various filters to remove noise and enhance contrast.

3. **Segmentation:** The images are segmented using Region Proposal Network (RPN), which identifies potential regions of interest in the images.
4. **Feature Extraction:** The segmented regions are further processed using Grey-Level Co-occurrence Matrix (GLCM) to extract relevant features and texture information.
5. **Classification:** The extracted features are used to train a Convolutional Neural Network (CNN) to classify the manhole images into one of the four categories: close, open, broken, or no manhole.
6. **Prediction and Localization:** The trained CNN model is then used to predict the category of the new images and localize the position of the manhole in the image using You Only Look Once version 8 (YOLOv8).
7. **Web-based Interface:** The results of the prediction and localization are displayed in a web-based interface that allows maintenance personnel to easily identify and prioritize manholes for repair.

A Region Proposal Network (RPN) is employed in object detection to produce candidate bounding boxes that potentially hold objects. It takes feature maps from an input image and puts anchor boxes of different sizes and aspect ratios at every position. For every anchor, it predicts objectness score and bounding box coordinates. High-confidence proposals are then polished and fed into a detection network such as Fast R-CNN. The RPN is trained end-to-end with classification and regression losses.

The Grey-Level Co-occurrence Matrix (GLCM) is a statistical technique used for texture analysis of digital images. It measures the frequency of pairs of pixel values at a given distance and direction and constitutes a square matrix whose elements represent how often particular grey-level pairs occur. From the GLCM, texture features such as contrast, energy, homogeneity, entropy, and correlation are derived. These characteristics find extensive application in image classification, especially in remote sensing, industrial inspection, and medical imaging for the identification of minute texture variations.

A Convolutional Neural Network (CNN) is a deep learning framework applied for image classification, recognition, and segmentation. It approximates the visual cortex organization by extracting hierarchical representations from raw pixel information. CNNs employ convolutional layers with learnable filters to obtain features and pooling layers to down sample and reduce the dimensionality. The output is usually produced by fully connected layers, with a soft max activation function for classification. CNNs are very effective for big datasets and computer vision tasks.

YOLOv8 (You Only Look Once version 8) is an efficient and accurate object detection model that detects and classifies objects in images. It makes predictions of bounding boxes and class probabilities using a single neural network. The algorithm splits the image into a grid, predicting offset and class probabilities for every cell. YOLOv8 enhances previous versions with deeper networks, skip connections, and residual blocks, with improved accuracy and speed, especially for small objects. It's extensively used in applications such as autonomous driving and surveillance.

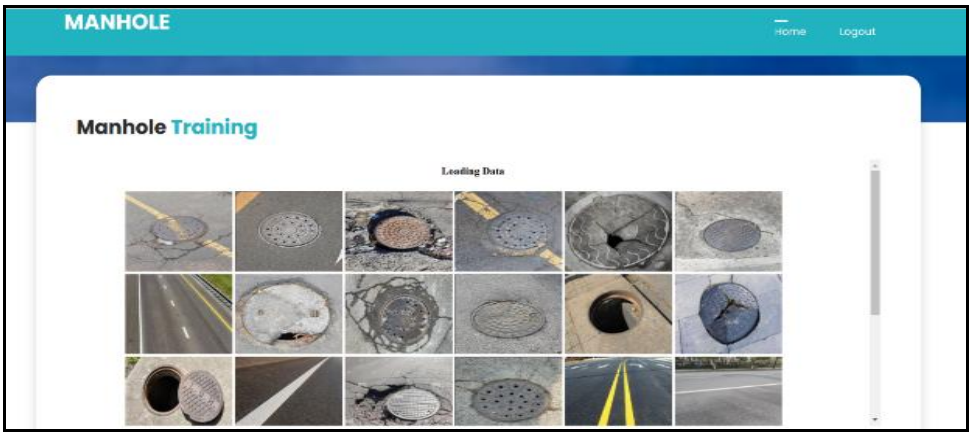

Fig 1: Dataset Uploading Page

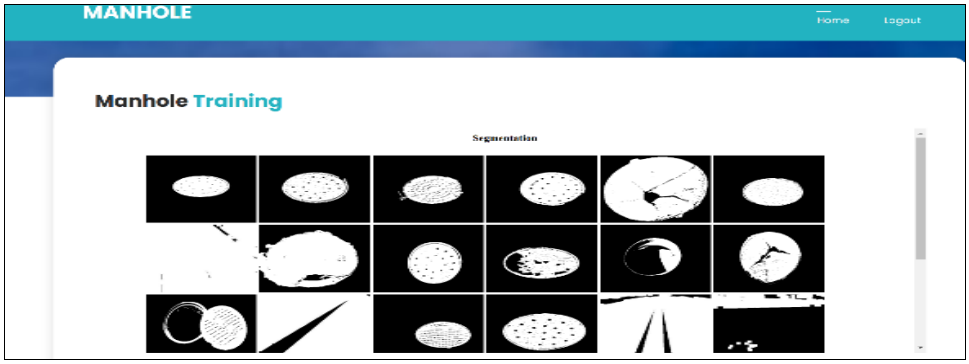

Fig 2: Segmentation Page

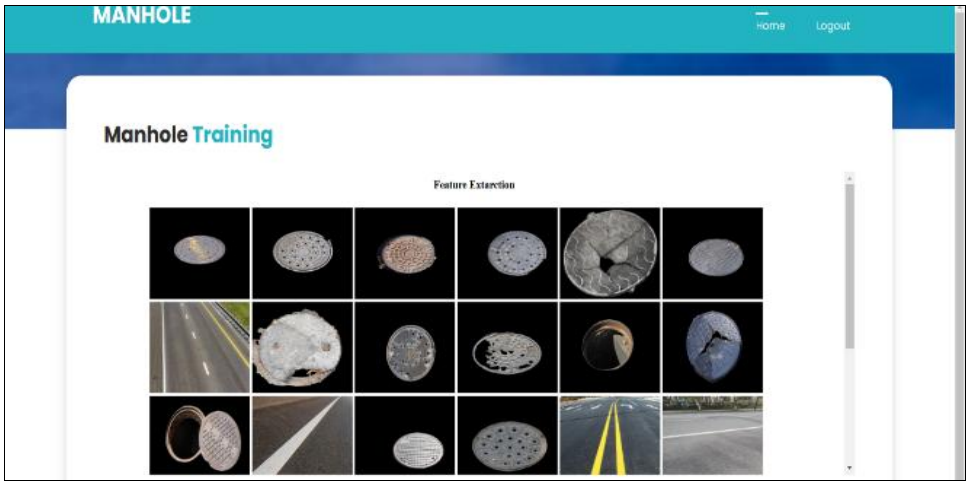

Fig 3: Feature Extraction Page

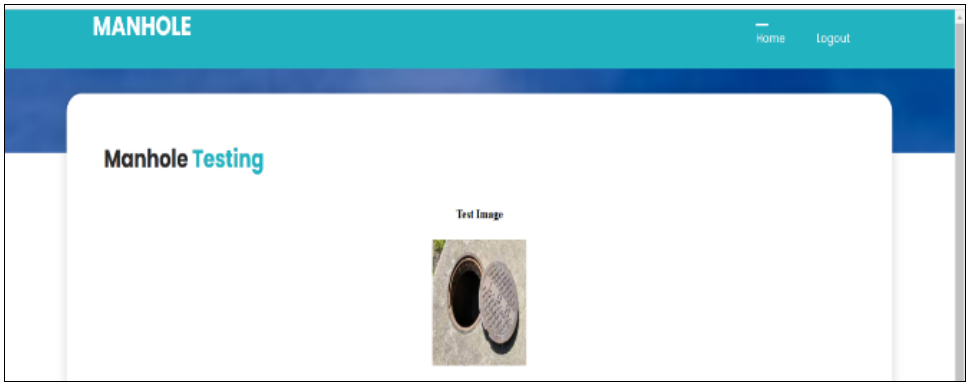

Fig 4: Input the Manhole Image

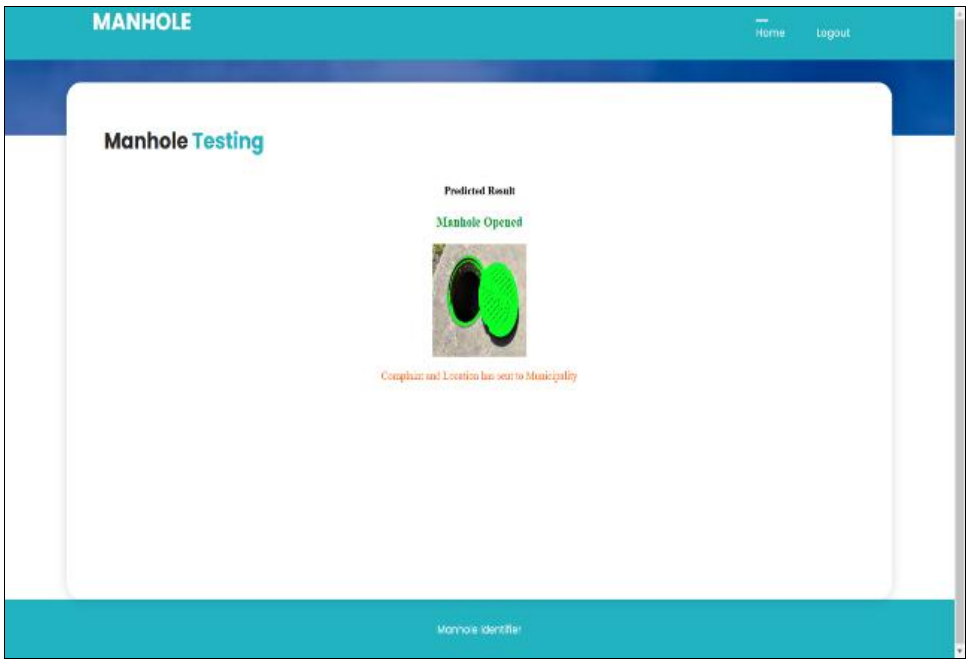

Fig 5: Predict Result

5. Conclusion

In conclusion, the development and implementation of the Manhole Predictor Web App represent a significant advancement in infrastructure maintenance practices. The proposed system of the project utilizing advanced deep learning algorithms such as Convolutional Neural Networks (CNN) for manhole classification, Region Proposal Network (RPN) for segmentation, and You Only Look Once version 8 (YOLOv8) for accurate prediction and localization, marks a significant advancement in infrastructure maintenance practices. The project has demonstrated the potential to revolutionize the inspection and maintenance of manhole

covers in urban environments. The accuracy and efficiency of the prediction model showcased in the project's results underscore its effectiveness in accurately classifying manhole covers and predicting their conditions. By providing municipalities and maintenance authorities with timely and precise information about the state of manhole covers, the web app enables proactive maintenance measures, ultimately enhancing urban safety and minimizing the risk of accidents. Furthermore, the user-friendly interface and seamless communication features of the web app facilitate efficient collaboration between users and municipal officers, streamlining the maintenance process and optimizing resource allocation. Thus this project represents a valuable tool for enhancing infrastructure management practices, contributing to safer urban environments, and laying the foundation for future advancements in smart city initiatives. With ongoing refinement and widespread adoption, the project holds the potential to significantly improve the maintenance and safety standards of urban infrastructure systems globally.

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