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Project Synopsis (2024-25) - Sem V

Artificial Intelligence based Pavement Condition Monitoring and Management System for Sustainable Urban Infrastructure

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Abstract

Our project aims to develop an AI-based pavement monitoring system that leverages real-time data collection and advanced analytics to identify and address pavement issues efficiently. The proposed system enables BMC (Brihanmumbai Municipal Corporation) to utilize its authorized autonomous vehicles equipped with wide angle panoramic cameras to monitor and gather comprehensive video and sensor data. The data is preprocessed and stored in a cloud-based infrastructure, ensuring scalability and accessibility. Machine learning models are then utilized to analyze the data, detect pavement problems, and generate actionable insights. These insights are visualized through interactive dashboards and analytical tools, enabling city administrators to make informed decisions. Additionally, the system integrates with a user interface dashboard that provides real-time statistics, alerts, and administrative controls. By automating the detection and management of pavement issues, our project aims to enhance the longevity and safety of urban roads while optimizing maintenance efforts and reducing costs.

Introduction

Urban infrastructure is a pivotal element in the seamless functioning of cities, directly influencing the quality of life and safety of its residents. In a densely populated metropolis like Mumbai, where pedestrian movement is significant, the condition of pavements becomes a crucial factor for ensuring public safety and accessibility. However, the current state of pavements in Mumbai is alarming, with numerous challenges such as illegal parking, encroachment by street vendors, poor maintenance, and improper waste disposal. These issues not only obstruct pedestrian pathways but also pose severe risks to pedestrian safety, as evidenced by recent statistics and reports highlighting frequent accidents and fatalities.

To address these challenges, our project, the "Artificial Intelligence-based Pavement Condition Monitoring and Management System for Sustainable Urban Infrastructure," leverages AI and image processing technologies to provide a real-time, automated solution for pavement monitoring and management. The project envisions equipping Brihanmumbai Municipal Corporation (BMC) garbage trucks with cameras to capture real-time images of pavements as they traverse the city. An advanced image processing model will analyze these images to detect various obstacles and issues on the pavements, such as illegal parking and obstructions by vendors.

By automating the detection and reporting of pavement issues, this system aims to enhance the efficiency of urban infrastructure maintenance. The project not only focuses on the technical aspects of image processing and AI but also considers the broader implications for urban planning and management. Through this innovative approach, we aspire to create a safer, more accessible urban environment, ultimately contributing to the sustainability and livability of cities like Mumbai.

Problem Statement

The maintenance and monitoring of urban pavements are essential for ensuring safe and efficient transportation for both vehicles and pedestrians. However, traditional methods of pavement inspection are labor-intensive, time-consuming, and prone to human error, leading to inefficiencies and delayed identification of critical issues. This results in increased maintenance costs, reduced pavement longevity, and potential safety hazards for the public. There is a pressing need for an innovative solution that can automate the process of pavement monitoring and provide real-time, accurate data to support timely and effective maintenance decisions. Our project aims to address these challenges by developing an AI-based pavement monitoring and management system that leverages advanced machine learning techniques and real-time data analytics to improve the accuracy, efficiency, and cost-effectiveness of pavement maintenance operations.

Proposed Solution

To address the challenges of pavement obstructions and ensure safer pedestrian pathways in Mumbai, we propose the development and implementation of an "Artificial Intelligence-based Pavement Condition Monitoring and Management System for Sustainable Urban Infrastructure." This solution leverages advanced technologies to provide a real-time, automated approach to pavement monitoring and management. The proposed system involves several key components and processes:

1. **Integration with BMC Garbage Trucks**:

   Equip Brihanmumbai Municipal Corporation (BMC) garbage trucks with high-resolution cameras to capture images of pavements across the city during their routine operations. Utilize existing routes and schedules of garbage trucks to ensure comprehensive coverage of the city's pavements without incurring additional operational costs.

2. **Image Capture and Transmission**:

   Implement robust image capture mechanisms to ensure clear and consistent image quality under varying environmental conditions (e.g., different lighting and weather). Use wireless transmission technology to send the captured images to a centralized server for processing.

3. **AI and Image Processing Model**:

   Develop and train a sophisticated image processing model using machine learning techniques to analyze the captured images. The model will be capable of detecting various pavement issues, including illegal parking, encroachments by vendors, poor maintenance conditions, and improper waste disposal. Implement real-time processing capabilities to quickly identify and categorize issues as they are detected.

4. **Data Management and Reporting System**:

   Create a centralized database to store the analyzed data, including images and identified issues. Develop a user-friendly interface for municipal authorities to access real-time reports and visualizations of pavement conditions. Include functionality for generating automated alerts and notifications to relevant departments for prompt action on detected issues.

5. **Actionable Insights and Decision Support**:

   Provide actionable insights and recommendations based on the analysis to aid municipal authorities in making informed decisions for pavement maintenance and management. Enable historical data analysis to identify recurring issues and prioritize areas requiring urgent attention.

Block Diagram

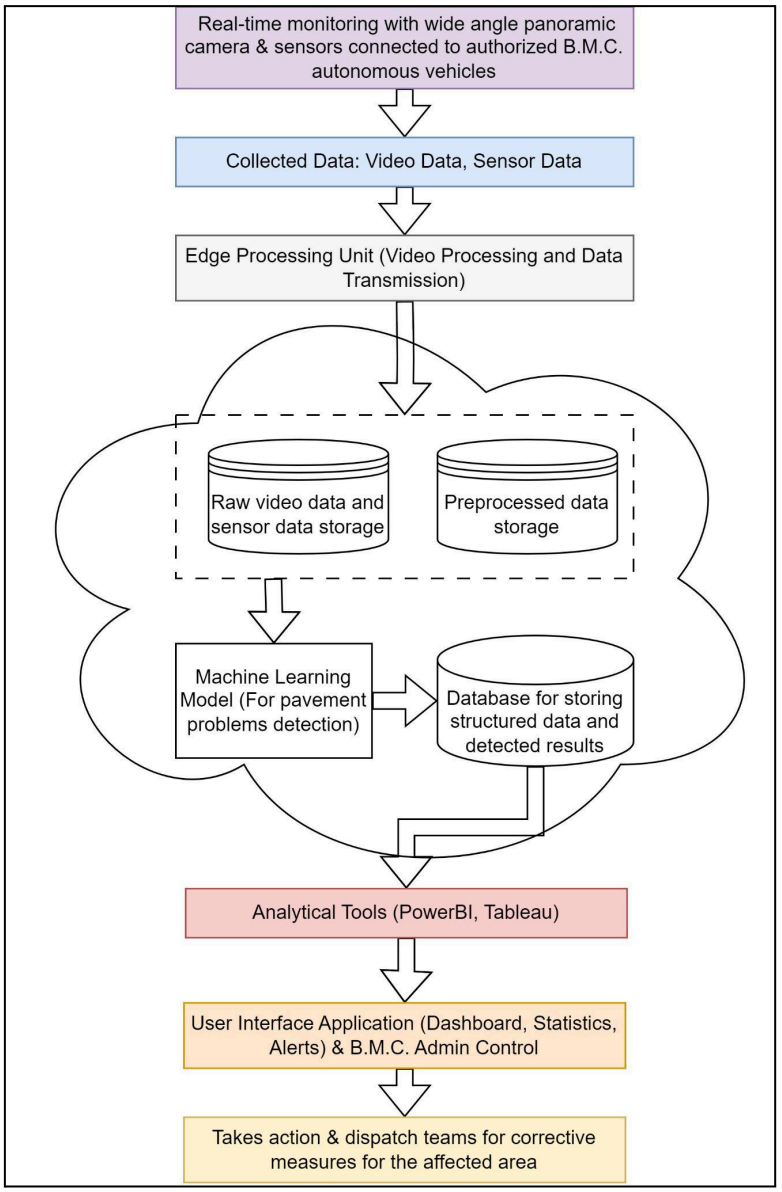

Fig. 1. Block diagram of the Proposed AI-based Pavement Monitoring System

Methodology

1. Data will be collected via B.M.C. autonomous vehicles, equipped with wide-angle panoramic cameras and various sensors that traverse the city's streets to continuously capture high-resolution video footage and sensor readings, providing comprehensive data on pavement conditions.

2. The collected data will be transmitted to an Edge Processing Unit where initial processing will take place to reduce data volume. This involves: (1) Frame selection, (2) Resolution adjustment, (3) Preliminary anomaly detection. These steps should ensure efficient data transmission and storage by filtering out irrelevant information.

3. Processed data will be temporarily stored in local storage units, categorized into:
   a. Raw Data Storage: Immediate storage of raw video footage and sensor readings.
   b. Preprocessed Data Storage: Storage of data after preliminary processing at the edge.

4. Preprocessed data will be fed to a machine learning model, which is trained using supervised learning techniques on a benchmarked dataset of pavement conditions. This model will detect and classify pavement issues such as obstructing trees, lamp posts, garbage, shanties, etc.

5. The results from the machine learning model, including detected pavement issues and associated metadata, will be stored in a structured database optimized for fast retrieval and efficient storage. This organized database facilitates systematic recording and further analysis of pavement conditions.

6. Using analytical tools such as PowerBI and Tableau, the structured data will be visualized and analyzed. These tools generate detailed reports and dashboards that provide insights into:
(1) The extent of pavement issues, (2) Severity levels, (3) Distribution patterns
This analysis will help stakeholders identify trends in pavement conditions over time.

7. A user-friendly dashboard will be developed to offer real-time monitoring and management capabilities. Key features include:
   a. Dashboards: Real-time data and trend displays on pavement conditions.
   b. Statistics: Detailed statistical analyses and reports.
   c. Alerts: Notifications for immediate attention to detected pavement issues.
   d. Centralized Admin Control: Authorized user management of system settings, data review, and initiation of corrective actions.

8. Based on insights and alerts from the user interface application, decisions will be made to dispatch maintenance teams to address identified pavement problems.

Hardware, Software and tools Requirements

Hardware	Software
Wide-angle panoramic cameras, Storage Devices (Onboard SSDs), Centralized servers or cloud storage, Wireless transmission devices (e.g., 4G/5G modules), Processing Units, High-performance servers or cloud-based instances with GPUs, GPS modules, Power supply solutions, Sensors	AI Frameworks (TensorFlow, PyTorch), Image Processing (OpenCV), Databases, Cloud Services (Cloud Storage, Cloud Compute Engine), Development Tools IDEs (Visual Studio Code, PyCharm, Jupyter Notebook), Version control (Git/Github), Data Visualization Tools (PowerBI, Tableau)

Proposed Evaluation Measures

1. **Accuracy of Obstacle Detection Metrics**: Precision, Recall, F1 Score
2. **Processing Time Metri**c: Average Processing Time per Image
3. **Data Transmission and Storage Efficiency Metrics**: Data Transmission Rate, Storage Utilization
4. **Maintenance Response Time Metric**: Average Response Time to Resolve Issues

Conclusion

In conclusion, the proposed "Artificial Intelligence-based Pavement Condition Monitoring and Management System" offers a sophisticated approach to addressing the prevalent challenges faced by urban infrastructure in Mumbai. By integrating advanced AI and image processing technologies with real-time monitoring through equipped garbage trucks, the system aims to enhance pavement safety and maintenance efficiency. The solution promises to improve pedestrian safety, streamline maintenance operations, and contribute to the overall sustainability of urban infrastructure, thereby creating a safer and more accessible environment for city residents.

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