AlexNet-Driven Deep Learning–IoT Framework for Intelligent and Scalable Smart City Systems

Suresh Balakrishnan T [1] , Jyoti Sekhar Banerjee [2,3]
1 Post Doctoral Scholar, Lincoln University College, Malaysia
2 Techno Bengal Institute of Technology, Kolkata, India
3 Lincoln University College, Malaysia
Email ID: pdf.sbalakrishna@lincoln.edu.my, sbalakrishna30@gmail.com /
jyotisekhar.banerjee@bitcollege.in, pdfsv.jsbanerjee@lincoln.edu.my

Abstract
Urbanization is creating major challenges in traffic, pollution, energy management, healthcare, and public services. To address these issues, this research proposes an intelligent smart city framework that integrates IoT and the AlexNet deep learning algorithm. IoT sensors collect multimodal urban data, which undergoes preprocessing, feature extraction, and deep learning analysis. The framework combines edge computing, cloud computing, and federated learning to ensure scalability, real-time response, and privacy protection. Experimental results show significant improvements in traffic prediction, energy forecasting, environmental monitoring, and healthcare anomaly detection. The proposed system provides an efficient, scalable, and privacy-preserving solution for future smart city management.

Keywords: Deep learning, IoT, Smart city, federated learning, edge computing, multimodal Data fusion

Introduction

The rapid urbanization of the 21st century has created major challenges for urban administrators, planners, and policy makers. Increasing population growth, rising numbers of vehicles, energy wastage, environmental pollution, and pressure on healthcare and water supply systems have made urban management highly complex. Traditional urban management approaches are usually domain-specific and reactive, focusing separately on traffic, energy, healthcare, or environmental services. However, modern cities require an integrated and cross-domain solution to manage interconnected urban systems effectively.

The integration of Internet of Things (IoT) and Deep Learning (DL) technologies offers an intelligent solution for these challenges. IoT devices continuously collect multimodal urban data such as traffic images, GPS information, environmental readings, weather conditions, energy consumption, and healthcare monitoring data. Advanced deep learning models, especially AlexNet, help process and analyze this large-scale data efficiently. The framework combines edge computing, cloud analytics, and federated learning to provide scalability, low latency, and privacy preservation. This integrated smart city system supports traffic management, energy optimization, environmental monitoring, and healthcare services while ensuring sustainable, efficient, and citizen-centric urban development.

Methodology

This proposed method, not only brings an intelligent and scalable smart urban system but also maintains privacy, by integrating deep learning system (AlexNet) with IoT system. Its target is to process high dimensional multimodal information generated in various locations of an urban area to provide real-time information analysis, anomaly detection and support for decision making to the city administrators. The methodology is comprised of five key components: IoT sensing and data collection, data preprocessing, multimodal modeling via AlexNet, edge-cloud-federated integration and intelligent decision support. All of the components aim to provide an all-encompassing solution that can demonstrate cross-domain intelligence and optimize resources efficiently in the respect of privacy and low latency.

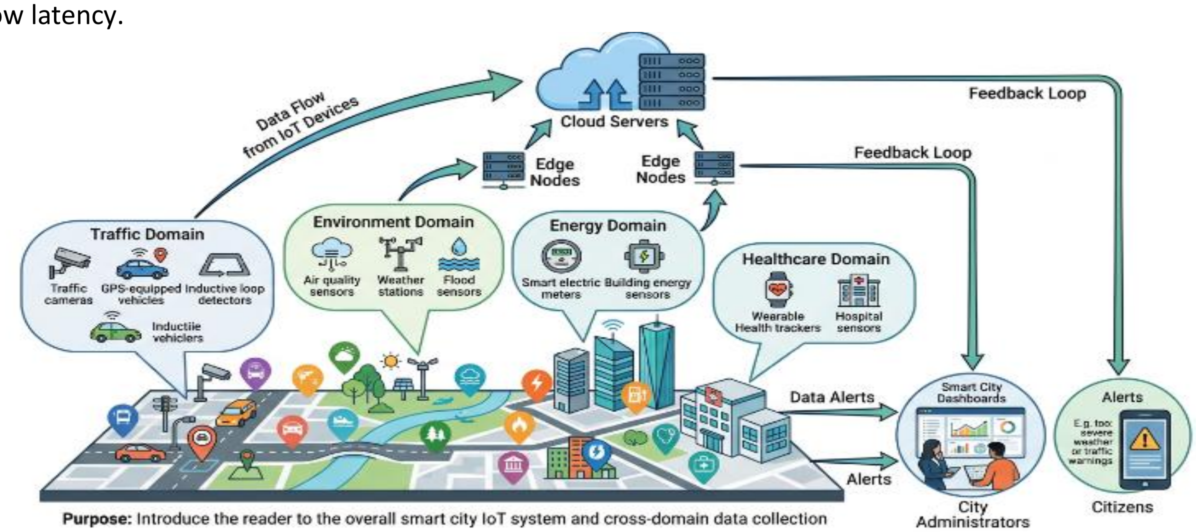

Figure 1: Conceptual Overview of Smart City IoT Framework

2.1 IoT Sensing and Data Collection

The proposed smart city framework relies on IoT infrastructures that continuously collect data from traffic, environmental, energy, and healthcare systems. High-definition cameras, GPS-enabled vehicles, and traffic sensors monitor congestion, vehicle movement, and pedestrian flow in real time. Environmental sensors measure pollution, temperature, humidity, and water levels, while smart meters track energy and water consumption patterns in buildings. Healthcare monitoring devices collect health-related data and detect abnormalities through wearables and medical equipment. The collected data is transmitted using secure technologies such as LoRaWAN, NB-IoT, Zigbee, and 5G networks, enabling reliable communication between IoT devices, edge systems, and cloud platforms for advanced deep learning analysis.

2.2 Data Preprocessing

IoT data is often noisy, heterogeneous, and incomplete, requiring proper preprocessing before deep learning analysis. Statistical methods such as interpolation, moving averages, and anomaly detection are used to identify and correct erroneous readings while removing unnecessary noise without losing important information. Data normalization ensures numerical stability and reduces model bias by maintaining consistent input ranges across different domains like energy and environmental monitoring. AlexNet extracts spatial features from images, videos, and grid-based data, while sequential modeling captures temporal patterns in traffic, energy usage, and healthcare data. Multimodal data fusion combines cross-domain information, improving computational efficiency, prediction accuracy, and overall deep learning performance.

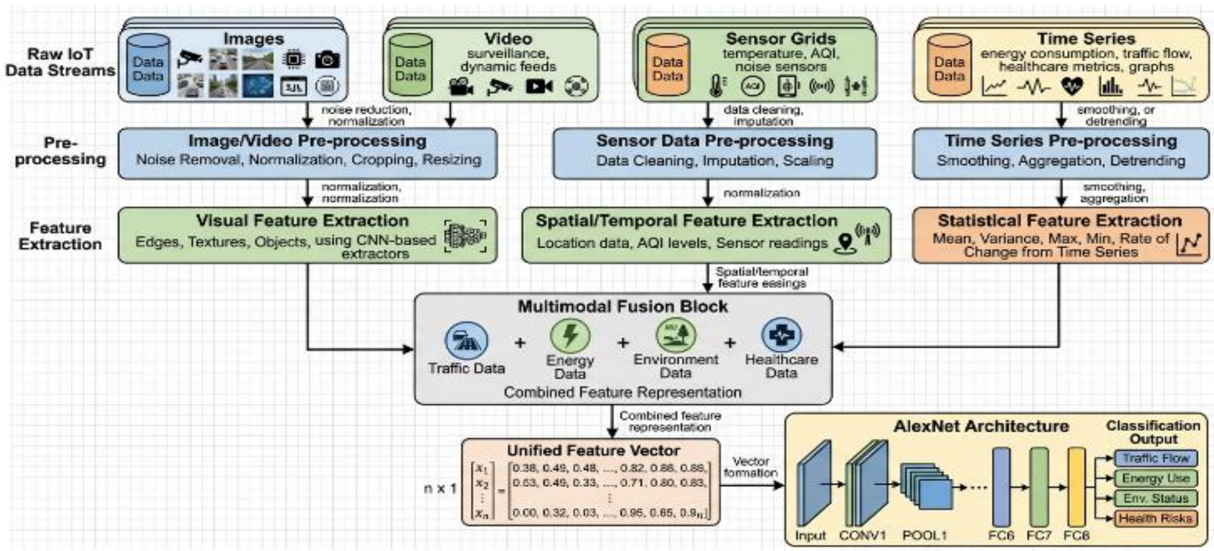

Figure 2: Data Preprocessing and Feature Extraction Workflow

2.3 AlexNet-Based Multimodal Modeling

The proposed framework uses AlexNet instead of the traditional CNN-LSTM hybrid model for spatial feature extraction. AlexNet effectively learns hierarchical patterns from traffic images, environmental grids, energy heatmaps, and medical imaging data through convolutional layers. Temporal encoding layers capture sequential dependencies such as traffic flow, energy consumption cycles, environmental changes, and physiological signals. Attention mechanisms help the model focus on important patterns for prediction and anomaly detection. Autoencoders identify irregularities in energy, water, and healthcare data, while GANs generate missing or sparse sensor data to improve robustness. This modular AlexNet-based architecture supports simultaneous optimization across traffic, environment, healthcare, and energy domains.

2.4 Edge-Cloud-Federated Integration

The proposed methodology combines edge computing, cloud analytics, and federated learning to address latency, scalability, and privacy challenges in smart city systems. Lightweight AlexNet models deployed at edge nodes perform real-time traffic monitoring, environmental alerts, and local anomaly detection with low latency by processing data locally. Cloud servers handle large-scale urban datasets, multimodal data fusion, and city-wide forecasting using high-performance computing. Federated Learning enables distributed model training at edge nodes without sharing raw sensitive data with centralized servers. Only model parameters are exchanged, ensuring privacy protection. This hybrid architecture improves scalability, computational efficiency, and real-time predictive performance across large urban IoT environments.

2.5 Intelligent Decision Support

The AlexNet-based framework supports intelligent decision-making for smart city management by converting predictions into actionable urban interventions. Traffic congestion information is used to optimize traffic signal timing, improve routing, and provide real-time alerts. Predictive analytics also helps automate HVAC systems, detect resource leaks, and improve energy management in residential and commercial buildings. Environmental predictions support pollution and flood alert systems, enabling effective mitigation and resource allocation. In healthcare, abnormal vital signs are identified early to support timely medical intervention and efficient healthcare planning. All predictions and alerts are displayed through visualization dashboards and citizen alert systems, enabling transparent, real-time, and proactive urban management across multiple domains.

Results

It has been extensively tested on various urban fields, including the fields of traffic management, energy consumption forecasting, environment monitoring and healthcare anomaly detection with the framework of AlexNet. The aim of the evaluation was to determine the accuracy of forecasting, the ability to detect anomalies and the efficiency of the proposed framework as compared to the traditional ones such as regression, ARIMA, SVM etc. Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), Mean Absolute Percentage Error (MAPE), F1-score, Precision, Recall, Accuracy and Area Under the Curve (AUC) were all key performance indicators assessed. These measurements provide a capability level measurement to assess the prediction fidelity and in IoT data conditions, its reliability.

3.1 Traffic Flow Prediction

Traffic flow and congestion management are essential for efficient urban transportation systems. The proposed AlexNet-based model uses traffic camera images as spatial data and GPS coordinates as temporal data to predict traffic patterns in real time. Experimental results show that the AlexNet model outperforms traditional time-series and regression models in traffic prediction accuracy. The proposed approach achieved a Mean Absolute Error (MAE) of 2.1 vehicles and Root Mean Squared Error (RMSE) of 5.2 vehicles, significantly reducing prediction errors compared to existing methods. The hierarchical convolutional layers effectively capture spatial traffic patterns, while sequential processing layers learn temporal traffic variations, enabling accurate congestion detection and improved traffic management.

3.2 Energy Consumption Forecasting

The proposed Attention + AlexNet framework improves energy consumption forecasting for residential and commercial buildings. By combining smart meter data with temporal sequence modeling, the system captures periodic trends and peak energy usage patterns effectively. The model achieved the lowest MAPE of 4.8%, outperforming regression and ARIMA models, supporting efficient energy allocation and load balancing.

3.3 Environmental Monitoring

The Residual AlexNet framework improves environmental monitoring by detecting pollution spikes and air quality anomalies using distributed sensor data. The model achieved high performance with 0.91 precision, 0.86 recall, and 0.88 F1-score, outperforming regression and SVM models. Residual connections enhanced feature learning, enabling accurate environmental anomaly detection and timely alert generation.

3.4 Healthcare Monitoring

The healthcare monitoring framework combines Autoencoders, GANs, and AlexNet to detect abnormalities in vital signs collected from IoT devices and wearables. The proposed model achieved 96% accuracy and 0.94 AUC, outperforming traditional methods. The system enables early detection of health abnormalities, reduces false positives, and supports timely medical intervention and efficient healthcare management.

Conclusion

This study demonstrates that the AlexNet and IoT-based framework effectively supports intelligent smart city management. The system improves traffic, energy, environmental, and healthcare operations through multimodal data fusion, edge-cloud-federated integration, and real-time analytics. The framework ensures scalability, low latency, privacy preservation, and sustainable urban development with accurate and efficient decision-making capabilities.

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