Edge-Computing Video Analytics for Real-Time Traffic Monitoring in a Smart City: A Case Study Analysis

A. Introduction and Objectives

The Liverpool Smart Pedestrians project aimed to develop and implement an intelligent edge-computing system for real-time pedestrian monitoring in urban environments. The primary objectives included:

- Development of an efficient edge-computing device for real-time video analytics
- Implementation of privacy-preserving pedestrian detection and tracking
- Validation of the system in both indoor and outdoor environments
- Support for urban planning decisions through data-driven insights

The project addressed several urban planning challenges, including pedestrian flow optimization, public safety enhancement, and the need for real-time data collection without compromising privacy.

B. Methodology

The project employed a systematic approach to sensor development and deployment:

1. Hardware Selection and Integration:
   - NVIDIA Jetson TX2 platform chosen for edge computing capabilities
   - Integration of camera modules and networking components
   - Consideration of power efficiency and environmental durability

2. Software Development:
   - Implementation of YOLO V3 algorithm for object detection
   - Development of custom tracking algorithms
   - Integration of data processing and transmission protocols

Key requirements included:
- Real-time processing capabilities
- Privacy preservation through edge computing
- Weather resistance and durability
- Low power consumption
- Cost-effectiveness for large-scale deployment

C. Technology and Implementation

The technical implementation centered around two main components:

1. Hardware Platform:
   - NVIDIA Jetson TX2 provided optimal balance of processing power and energy efficiency
   - GPU acceleration enabled real-time video processing
   - Integrated wireless connectivity supported data transmission

2. Software Stack:
   - YOLO V3 algorithm modified for pedestrian detection
   - SORT algorithm implemented for object tracking
   - Custom software developed for data aggregation and transmission
   - PyTorch framework utilized for deep learning implementation

The edge-computing paradigm proved essential by:
- Reducing network bandwidth requirements
- Ensuring data privacy through local processing
- Minimizing latency in detection and tracking
- Enabling scalable deployment

D. Validation and Performance

The validation experiments demonstrated robust system performance:

Performance Metrics:
- Detection accuracy: >90% in various lighting conditions
- Processing speed: Real-time analysis at 30 FPS
- System utilization: Efficient resource management with <80% GPU usage
- Power consumption: Sustainable operation within design parameters

Testing Scenarios:
- Controlled indoor environments
- Outdoor deployments under varying weather conditions
- Different times of day and lighting conditions
- Various pedestrian density scenarios

E. Real-World Applications

The system was deployed in two distinct scenarios:

1. Indoor Emergency Evacuation:
   - Successfully tracked pedestrian movement patterns
   - Provided real-time occupancy monitoring
   - Supported emergency response planning
   - Demonstrated system reliability in controlled environments

2. Outdoor Deployment in Liverpool:
   - Monitored pedestrian flows in urban areas
   - Generated valuable data for urban planning
   - Proved system durability in outdoor conditions
   - Validated privacy-preserving capabilities

F. Challenges and Future Work

Key Challenges:

1. Environmental Factors:
   - Weather impact on sensor performance
   - Varying lighting conditions affecting detection accuracy
   - Physical durability requirements

2. Technical Limitations:
   - Processing power constraints
   - Battery life optimization
   - Network connectivity issues

Future Work Recommendations:

1. Technical Improvements:
   - Integration of newer AI models for improved accuracy
   - Implementation of advanced tracking algorithms
   - Enhancement of power efficiency

2. System Expansion:
   - Integration with other smart city systems
   - Development of advanced analytics capabilities
   - Implementation of predictive modeling

Recent Technological Developments (2019-2024):

- Advanced edge AI processors (e.g., NVIDIA Jetson Orin)
- Improved object detection models (YOLO V7, V8)
- Enhanced 5G connectivity options
- More efficient power management solutions