AI-BASED ADAPTIVE TRAFFIC SIGNAL OPTIMIZATION UNDER IRREGULAR TRAFFIC CONDITIONS

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Abstract

Urban traffic in Sri Lanka is significantly affected by irregular conditions caused by accidents, peak-hour congestion, and emergency vehicle movements. Non-adaptable conventional fixed-time traffic signal systems result in delays, fuel wastage, and higher CO_2 emissions. This study presents an AI-based adaptive traffic signal control system to optimize irregular and mixed traffic conditions, using the Nugegoda-Delkanda intersection in Sri Lanka as a case study. In the perception phase, 04 USB cameras (720 pixels, 30 fps) were used to capture live traffic at the intersection. The YOLOv26 (toy: 7,255, 05; emergency: 4,180, 03; non-emergency: 5,300+, 11), accompanied by Centroid Tracker, was used to detect vehicle position, class, speed, and waiting time. In the decision phase, traffic data was converted into a 287-dimensional state vector (spatial-240, context-43, LSTM queue predictor-4). Subsequently, a Dueling Double Deep Q-Network agent incorporating Squeeze-and-Excitation blocks & Prioritized Experience Replay was trained in SUMO to decide whether to change or hold the traffic signal. In the actuation phase, a prototype was developed with two ESP32 microcontrollers, and commands were communicated via TCP to control the straight and right-turn signals independently. The developed system supported reducing vehicle waiting times by 28.9% with respect to fixed-time control, while the three-seed average reduction was 11.0%. The spatial matrix was the most significant component in ablation tests; removing it reduced performance by 5.4%, followed by emergency vehicle (4.7%) and scalar vector (2.5%) features. Within 200 ms, the lane-aware emergency override system recognized emergency vehicles and changed the appropriate signal in 500 ms. Validation on a scaled physical prototype, the system achieved real-time operation at ~30 fps, an RL inference time <10 ms, and a decision latency of ~120 ms. Hence, complicated and irregular road conditions can be handled using deep reinforcement learning with improved efficiency, while reducing fuel wastage and CO_2 emissions.

Keywords: Adaptive Traffic Signal Optimization, Deep Reinforcement Learning, Dueling DQN, Irregular Traffic Conditions, SUMO Simulation