A Deep-Reinforcement Learning Eco-driving application for Providing Sustainable Signalized Intersections: Prioritized Experience Replay, Target Network, and Double Learning Techniques

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Introduction

The USA is the world's major consumer of petroleum, accounting for more than 20% of the global consumption. Since the 1980's, the industrial, residential and electric power sectors within the USA have been maintaining almost the same amount of consumed petroleum, unlike the transportation sector where the consumption has been steadily increasing . In fact, the transportation sector is currently the major consumer of the US national petroleum with a share of about 75%. Moreover, since 2000, the transportation sector has been the largest carbon dioxide emitter, which created an urgent need for developing applications for making the transportation sector more sustainable in terms of fuel consumption and greenhouse emissions. A good example of these applications is the "eco-driving", which aims to reduce vehicles fuel consumption levels by achieving a smooth speed profile through reducing unnecessary acceleration, deceleration, and idling situations. In the USA, about 2.8 billion gallons of gasoline are consumed annually because of idling and slowing-down at intersections. The rapid progress in connected vehicles and communication technology made communication between vehicles and infrastructure (V2I/ I2V) possible. This type of communication allows traffic signals to transmit their Signal Phasing and Timing (SPaT) information to vehicles such that vehicles can broadcast information on their location, speed, and acceleration. This helps researchers develop more efficient eco-driving applications for vehicles passing through a signalized intersection.

Eco-driving is a complex control problem where the driver's actions are guided over a period of time or distance so as to optimize fuel consumption. Moreover, the non-linear models for fuel consumption add to the complexity of solving this control problem. The literature review shows that many algorithms developed in previous studies have had mixed success in solving this problem. This is attributed to the need for costly computational resources, the difficulty in locating the global minimum due to multiple local minima, or the assumption of perfect knowledge of the simulated environment, which is not applicable in most cases.

Objective

This paper develops a Deep Reinforced Learning (DRL) algorithm for solving the eco-driving control problem while overcoming the above-mentioned limitations. The DRL algorithm is capable of maintaining more sustainable intersections by reducing the levels of fuel consumption and greenhouse emission.

Methodology

Reinforced Learning is a machine learning paradigm that mimics the human learning behavior where an agent attempts to solve a given control problem just by interacting with the environment. The agent does not need prior knowledge of the environment dynamics or the transition state probability. The agent just needs to access a set of samples collected online or offline. In reinforced learning, no assumptions are needed for solving the control problem except the Markov property assumption which holds in most cases. In its early implementations, the application of reinforced learning was limited to solving control problems with limited states and actions. Recently, with the advent of powerful computing techniques, researchers implemented Deep Artificial Neural Network (DANN) for approximating the space of states and actions for larger environments, and reinforced learning became now more capable of solving complex control problems through Deep Reinforced Learning (DRL). However, many studies reported the instability of DRL learning, specifically while training the DANN. Therefore, to account for such potential instabilities, three novel innovative techniques were implemented namely, prioritized experience replay, target network, and double learning. The DRL algorithm was coded using Python and interfaced with PTV-VISSIM platform via VISSIM-Com environment, and the model was run to simulate the traffic operation at a typical signalized intersection.

Results

The simulation results indicated the effectiveness of the developed model in providing more sustainable semi-actuated intersections in terms of fuel consumption and emissions. Results indicated that the vehicles controlled by the agent through a 400-m control section experience saving in fuel consumption up to 17.5% compared with that consumed by uncontrolled vehicles. Yet, these reductions are not associated with any travel time delays. Additionally, the controlled vehicles experienced a reduction in acceleration noise by 16.9%. Such acceleration reductions are considered a good indication of improvement in vehicle emissions and traffic safety.

Conclusions

The advantage of solving the eco-driving problem through a DRL agent is twofold: first, the agent is able to solve complex problems without any prior knowledge of the system dynamics, and second, with the use of DANN, the agent can solve problems involving environments with large dimensions. Furthermore, the algorithm is currently being enhanced through an ongoing research to investigate the eco-driving problems for vehicles traversing multiple intersections.