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TRAJECTORY PLANNING FOR AUTOMATED PARKING SYSTEMS USING DEEP REINFORCEMENT LEARNING

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ABSTRACT−Deep reinforcement learning (DRL) has been successfully adopted in many tasks, such as autonomous driving and gaming, to achieve or surpass human-level performance. This paper proposes a DRL-based trajectory planner for automated parking systems (APS). A thorough review of literature in this field is presented. A simulation study is conducted to investigate the trajectory planning performance of the parking agent for: (i) different neural-network architectures; (ii) different training set-ups; (iii) efficacy of human-demonstration. Real-time capability of the proposed planner on various embedded hardware platforms is also discussed by the paper, showing promising performance. Insights of the use of DRL for APS are concluded at the end of the paper.

KEY WORDS : Deep reinforcement learning, Automated parking systems, Trajectory planning

NOMENCLATURE

a : action
l : length
$L(s, a)$: loss function
$Q(s, a, \theta)$: action-value function
r : reward
s : state
θ : optimal parameter
γ : discount factor
β : slip angle
π : policy
ψ : yaw angle
δ : steering angle of front axle

SUBSCRIPTS

i : index
N : total training number
R : reserved
t : time step

1. INTRODUCTION

Autonomous driving systems have been intensively investigated by industry and academia in most recent years. These systems typically adopt camera, radar or lidar sensor signals as input, assisting or replacing drivers under some specific driving scenarios. Most recent advances of commercialized systems include: highway pilot (HWP), traffic jam pilot (TJP), and parking pilot (PP), etc. Such piloted driving systems need precise environment perception and comprehensive decision-making, intuitively fitting with the nature of deep reinforcement learning (DRL).

Deep reinforcement learning, a combination of deep neural network and reinforcement learning, has achieved or surpassed human-level performance in Atari (Mnih *et al*., 2013) and Go (Sliver *et al*., 2016) games. Besides the well-known success in gaming, DRL has also been attempted by some automated-driving related applications.

For driver-assistance, Chae *et al*. (2017) proposed an autonomous braking system using a deep Q-network agent trained via a Markov decision process (MDP). For automated-driving, Mnih *et al*. (2016) applied DRL to explore the finest driving policy according to a reward function calculated from the vehicle's heading angel and velocity. They trained a three layer CNN with An Asynchronous Actor Critic (A3C) framework to optimize vehicle control commands. Sallab *et al*. (2016, 2017) proposed a general DRL-based framework and demonstrated its efficacy for lane-keeping scenarios in simulation. More recently, Kardell and Kuosku (2017) proved that driving policy obtained by a DRL-agent outperformed its counterpart learned by a supervised-agent in some tricky driving scenarios. Shiba (2017) proposed a deep parking implementation with deep reinforcement learning, achieving good parking performance but consuming tens of days' training. Jaritz *et al*. (2018) present an end-to-end race driving with DRL, which

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