

Recent Advances in Digital Twin–Based Learning, Perception and Reasoning for Self-Driving Vehicles

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Abstract:

The ongoing advancement of autonomous driving technologies necessitates robust frameworks for perception, decision-making, and continuous system improvement within complex, dynamic environments. This research presentation introduces a digital twin–based learning and reasoning framework for self-driving vehicles, which incorporates real-time physical data and virtual emulations to facilitate adaptive, data-driven intelligence. The system constructs a high-fidelity digital replica of the vehicle and its environment, continuously updated via on-board sensors, vehicular networks, and cloud infrastructure. This dynamic integration enables the digital twin to support ongoing learning, predictive modeling, and situational reasoning while maintaining uninterrupted real-world operations. Within the twin environment, machine learning and knowledge-based reasoning modules process sensor data, simulate various scenarios, and refine driving policies across a range of conditions, including rare edge cases not easily replicated in physical testing. This method contributes to improved safety, adaptability, and reliability of decisions and diminishes the cost and risk associated with physical experimentation. Experimental results demonstrate that digital twin–enabled learning significantly enhances perception accuracy, path planning efficiency, and fault diagnosis compared to conventional models. The findings underscore the pivotal function of digital twins as intermediaries between physical vehicles and intelligent virtual agents, advancing the development of safer and continually improving autonomous driving for intelligent transportation systems.