# 論文 / 著書情報
# Article / Book Information

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# 論 文 要 旨

THESIS SUMMARY

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| 系・コース：<br>Department of, Graduate major in | 電気電子 系<br>電気電子 コース | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of （ 学術 ） |
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


Over the past two decades, digital twins (DTs) have driven significant advancements across various industrial domains, including manufacturing, aerospace, and healthcare. As digital representations of physical entities, DTs enable real-time monitoring, simulation, and optimization, allowing for improved decision-making and predictive capabilities. In recent years, with the rapid development of autonomous driving technologies and vehicle-to-everything (V2X) communications, the integration of DTs into vehicular platforms is poised to revolutionize smart mobility systems by enhancing connectivity, efficiency, and safety on the roads. The ability to create a synchronized and interactive digital counterpart of transportation systems ensures proactive responses to potential traffic incidents, thereby reducing delays and improving overall travel experiences. This thesis introduces a novel smart mobility digital twin (SMDT) platform designed to optimize the control of connected and automated vehicles (CAVs) over next-generation wireless networks.

The SMDT platform is implemented using state-of-the-art (SOTA) products such as CAVs and roadside units (RSUs), as well as emerging technologies like cloud computing and cellular V2X (C-V2X). By creating a comprehensive and dynamic virtual representation of the physical transportation environment, the SMDT enables real-time data exchange and interaction between vehicles, RSUs, and cloud servers. The platform serves as a bridge between real-world traffic conditions and computational intelligence, allowing for enhanced decision-making, predictive analytics, and seamless communication between smart entities in the V2X network. In Science Tokyo smart mobility field, a prototype SMDT system is deployed in a real-world environment, enabling real-time traffic DT modeling on the cloud plane.

One of the core applications of the SMDT platform is the development of a global DT-based CAV navigation system, aimed at improving traffic efficiency and safety. By optimizing vehicle route planning through real-time data analysis on the cloud server, the system provides CAVs with informed routing decisions based on real-time traffic conditions. Proof-of-concept (PoC) experiments are conducted to validate system performance. The performance of SMDT-based CAV navigation system is evaluated from two standpoints: (i) the rewards of the proposed navigation system on traffic efficiency and safety and, (ii) the latency and reliability of the SMDT platform. Large-scale traffic simulations using the SUMO platform demonstrate that the proposed SMDT significantly reduces average travel time and the probability of traffic congestion caused by unexpected incidents. Furthermore, experimental results indicate that the peak latency for DT modeling and route planning services is 155.15 ms and 810.59 ms, respectively, aligning with the 3rd Generation Partnership Project (3GPP) requirements for emerging V2X use cases. These findings validate the effectiveness of the proposed system in supporting real-time vehicle navigation and efficient route planning.

In addition to global navigation, the SMDT platform is also applied to a local DT (LDT)-assisted hybrid autonomous driving system for improving safety and efficiency in traffic intersections. By leveraging RSUs equipped with sensory and computing capabilities, the proposed system continuously monitors traffic, extracts human driving knowledge, and generates intersection-specific local driving agents through an offline reinforcement learning (RL) framework. When CAVs pass through RSU-equipped intersections, RSUs can provide local agents to support safe and efficient driving in local areas. Meanwhile, they provide real-time cooperative perception to broaden onboard sensory horizons. Hardware-in-the-loop (HiL) simulations and PoC tests validate system performance from two standpoints: (i) The peak latency for cooperative perception and local agent downloading are 8.51 ms and 146 ms, respectively, aligning with 3GPP requirements for V2X and artificial intelligence

(AI)/machine learning (ML) model transfer use cases. Moreover, (ii) local driving agents can improve safety measures by 10% and reduce travel time by 15% compared with conventional onboard systems. The implemented prototype also demonstrates reliable real-time performance, also fulfilling the targets of the proposed system design.

This thesis contributes to the field of smart mobility and autonomous driving by introducing an innovative platform that bridges the gap between global traffic optimization and localized autonomous driving support. By leveraging advanced AI algorithms, real-time data fusion, and next-generation wireless communications, the SMDT platform presents a holistic approach to enhancing road safety, reducing congestion, and improving overall transportation efficiency. The research findings underscore the transformative potential of DT-based solutions in the evolution of intelligent transportation systems (ITSs), setting the stage for future developments in cooperative autonomous driving and smart city infrastructure.

In conclusion, the SMDT platform represents a significant advancement in the domain of mobility DTs, offering a scalable and practical framework for integrating AI-driven decision-making into autonomous vehicle operations. Future research directions include expanding the capabilities of the SMDT to support multi-vehicle cooperative driving systems, incorporating causality modeling for improved predictive analytics, and exploring large-scale deployments in real-world urban environments. As autonomous driving technologies continue to mature, the adoption of DT-based solutions is expected to play a pivotal role in shaping the future of smart mobility and transportation systems.