Human-Centered Physical AI

Designing the Passenger Experience in Automated Vehicles: Proven UX Methods and Real-World Findings

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Key Words : Automated Vehicles, Passenger Experience, User Experience(UX) Design, Human-Centered Design, Participatory Design, Prototyping and User Testing, Simulator Validation, Trust and Acceptance

ABSTRACT

As vehicles become increasingly automated, the passenger experience becomes a key differentiator and a critical factor for acceptance. This talk highlights the strategic value of User Experience (UX) design in automated driving and demonstrates how different UX methods can be applied effectively across development stages. Drawing on several real-world projects, I will present four proven approaches: (1) Observation and surveys to understand user needs, expectations, and concerns; (2) Participatory design to co-create solutions with users and ensure relevance and acceptance; (3) Prototyping and user testing to evaluate interaction concepts, interfaces, and usability; and (4) Simulator and on-road validation to assess comfort, motion effects, trust, and overall experience in realistic contexts. By comparing insights from these methods, I will show how each contributes unique value and how they can be combined to reduce development risks, improve safety and comfort, and increase user trust and adoption.

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강화학습 기반 Steer-by-Wire 제어기술 및 일반도로 환경 검증

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Reinforcement Learning-Based Steer-by-Wire Control Technology and General Road Environment Validation

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Key Words : Reinforcement Learning(강화학습), Vehicle Control(차량 제어), SbW(전자식 조향 시스템), Steering System(조향시스템), Road Environment Validation(도로 환경 검증)

ABSTRACT

Conventional Steer-by-Wire (SbW) control has mainly relied on linear control theory or model-based control methods such as Model Predictive Control (MPC). However, these approaches have limitations in fully capturing nonlinear vehicle responses and often suffer from high computational complexity, which restricts their real-time applicability in diverse driving conditions. As a result, their control performance tends to degrade in nonlinear response regions, such as tire saturation, or under external environmental variations.

In this study, we propose a reinforcement learning–based SbW steering control technique that defines the driver's steering intention in terms of a target curvature and aims to accurately track it. The proposed method takes the vehicle's dynamic state information as input and generates steering commands through a reinforcement learning policy, trained to stably follow the target curvature. This enables the vehicle to maintain curvature-tracking performance that reflects the driver's intention even when entering nonlinear response regions.

The Soft Actor-Critic (SAC) algorithm was adopted as the learning framework, allowing efficient learning in continuous state and action spaces and achieving a robust control policy through a stable balance between exploration and exploitation. The performance of the proposed controller was validated using IPG CarMaker–based simulations across various scenarios representing typical road environments. The experimental results demonstrate that the reinforcement learning–based SbW controller outperforms conventional control methods in terms of target curvature tracking accuracy and vehicle stability, particularly maintaining robust steering control that faithfully represents the driver's intention even in nonlinear dynamic regions. This study presents a pathway toward the advancement of SbW control technology and its potential for real-world road implementation.

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End-to-End 자율주행 데이터 확보를 위한 시뮬레이터 기반 시나리오 자동 생성 및 의미론적 분류

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Simulator-Based Automatic Scenario Generation and Semantic Classification for End-to-End Autonomous Driving Data Acquisition

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Key Words : End-to-End Autonomous Driving(종단 간 자율주행), Coreset Selection(코어셋 선택), Frame-Level Semantic Selection(프레임 수준 의미 기반 선택), Data Efficiency(데이터 효율성), Importance Sampling (중요도 샘플링)

ABSTRACT

End-to-End autonomous driving requires large-scale and diverse driving data, but collection in real-world environments has limitations in terms of cost, safety, and event frequency. To solve this problem, this study proposes a pipeline that automatically generates scenarios based on simulators and maximizes data efficiency by removing low-value segments with limited training utility from generated and collected data. A scenario space parameterized by road structure, traffic density, weather, signal/regulation, interaction events (lane change, merges, pedestrian/bicycle sudden events, etc.) is defined; scenarios are automatically sampled, guided by coverage metrics and event distributions. Then, to train the end-to-end autonomous driving model, the scene is classified and annotated at the frame level through a semantic classifier, and an importance score is calculated by integrating scarcity, event intensity, and end-to-end autonomous driving model uncertainty information. Based on the score, importance sampling and coreset selection are performed to suppress duplicate frames and select samples with high learning contribution. The proposed method aims to secure wider scenario coverage under the same simulation resource while reducing the training data volume with frame-level semantic-based selection while without degrading policy performance. This pipeline presents a general procedure to increase the data efficiency and practicality of end-to-end autonomous learning by organically linking simulator-led data acquisition, semantic classification, and importance sampling/coreset selection.

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Physical AI를 활용한 운전 성향 기반 차량 부품 마모 및 거동 특성 해석

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Physical AI-Driven Analysis of Vehicle Component Wear and Dynamic Behavior According to Driving Styles

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Key Words : Driving style(운전 성향), Component wear(부품 마모), Dynamic behavior(차량 거동), Physical AI (Physical AI)

ABSTRACT

This paper presents a Physical AI-driven analysis of vehicle component wear and dynamic behavior under driving styles. Driving styles—typically categorized as defensive, normal, and aggressive—are abstract behavioral concepts, yet they play a vital role in influencing remaining useful life of chassis components and vehicle dynamics. It is known to be establishing a direct connection between such behavioral tendencies and measurable physical phenomena remains challenging. To address this limitation, a Physical AI-based framework is proposed that integrates driving-style classification, component wear modeling, and vehicle dynamics analysis. Physical AI serves as a medium for quantitatively interpreting and visualizing the interrelationship among driving style, component wear, and vehicle dynamics, thereby physically expressing how behavioral tendencies manifest as component degradation and dynamic responses. Driving styles were quantified using a driving-aggressiveness indicator and validated through spectral clustering of RGB feature vectors derived from an LSTM-Autoencoder. With successfully quantified driving styles, experimentally validated physical wear models from previous studies were used to derive the wear characteristics of key chassis components (e.g., brake pads and dampers), which were then implemented in a Digital Twin environment to reproduce variations in component degradation and vehicle behavior according to driving styles. As a result, it has been shown that, even under identical driving conditions, differences in driving style lead to distinct wear patterns, which in turn cause measurable changes in vehicle dynamics such as vibration, rolling, and braking performance. In particular, aggressive driving styles accelerate wear progression—damper degradation amplifies body vibration and rolling, while brake-pad wear leads to a noticeable decline in braking performance.

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도시 감지와 상호작용 관점에서의 인간 중심 스마트 모빌리티 연구

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Toward Human-Centered Smart Mobility: Urban Sensing and Interaction Perspectives

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Key Words : Urban sensing networks(도시 감지 네트워크), Multi-modal sensor data(이기종 센서 데이터), Human-urban interaction(인간-도시 인터랙션), External human-machine interfaces(외부 HMI)

ABSTRACT

The Stanford Center at the Incheon Global Campus (SCIGC) serves as Stanford University's flagship research hub in South Korea. Guided by its long-term vision to establish a smart city model, SCIGC conducts multidisciplinary research encompassing urban sensing, human–technology interaction, and sustainability. Among these efforts, SCIGC's research on smart mobility in urban environments focuses on developing mobility solutions tailored to the specific characteristics and needs of each city. Achieving this requires an accurate and dynamic understanding of the city's condition. To that end, SCIGC is advancing the development of Urban Sensing Networks through the integrated analysis of multi-modal sensor data. Data from mobile sensing platforms and infrastructure such as CCTVs and loop detectors are systematically analyzed and fused to enhance the precision of city- and traffic-monitoring systems.

Furthermore, realizing smart mobility goes beyond technological advancement alone; it also requires effective interaction between humans and mobility systems. SCIGC therefore conducts human-centered research on the interaction between people and autonomous vehicle technologies. Using a driving simulator, studies have been carried out on driver responses under semi- and fully autonomous driving conditions to improve in-vehicle human–machine interaction. External human–machine interfaces (eHMI) that facilitate communication between autonomous vehicles and pedestrians have also been examined through theoretical analyses and field tests. These research activities aim to enhance social acceptance and ensure the safe and sustainable integration of emerging mobility technologies within future urban environments.

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인간 중심 기반 적응형 협업을 위한 인간–로봇 상태 모델링의 통합 프레임워크

임치호*

An Integrative Framework of Human–Robot State Modeling for Human-Centered Adaptive Collaboration

Chiho Lim*

Key Words : Human-Robot Interaction(인간-로봇 상호작용), Human–Robot State Modeling(인간-로봇 상태 모델링), Bidirectional Interaction(양방향 상호작용)

ABSTRACT

Despite the growing adoption of industrial robots and intelligent mobility systems, research on Human-Robot Interaction (HRI) has largely remained one-directional, with most studies focusing on how robotic and mobility agents monitor and interpret human states. However, such approaches often overlook the robot's own state and its influence on the human partner's perception, decision-making, and trust. HRI should instead be understood as a bidirectional and dynamic system, in which the user's cognitive and physiological states can change depending on the robot's behavior or condition. To capture this reciprocal relationship, this study proposes an integrative framework that combines the User Agent Module and the Robot Agent Module. The User Agent Module represents the human side of interaction and includes real-time observation of physiological and behavioral indicators such as fatigue, attention, and engagement. The Robot Agent Module represents the robot's operational state and covers motion control, task performance, and behavioral feedback that affect the user's perception and trust. By integrating these two modules, the proposed framework establishes a mutually adaptive HRI structure that enables continuous state exchange and co-regulation between human and robot agents. To demonstrate this concept, this study presents empirical research on both the User Agent Module and the Robot Agent Module. By presenting studies on each module, the research highlights key considerations for achieving an integrated framework. Accordingly, the proposed approach provides a roadmap for future research toward the development of more robust human-centered HRI systems.

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