# 포스터 발표

# K-City 기반 Lv.4 자율주행 기술 검증 환경 고도화 방안 연구

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# A Study on the Advancement of K-City Testbed Environment for Testing & Validation of Lv.4 CAVs Technologies

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**Key Words :** K-City(자율주행 실험도시), VILS(Vehicle-In-the-Loop Simulation, 차량기반 교통상황 재현시스템), Virtual Simulation(가상 시뮬레이션), ODD(Operational Design Domain, 운행설계영역)

## ABSTRACT

In the global pursuit of accelerating autonomous vehicle (AV) commercialization, the New Assessment/Test Method for Automated Driving (NATM) has been adopted, comprising a three-phase validation process: virtual testing environments, controlled testbeds, and real-world living labs. Within this framework, Korea's K-City, managed by the Korea Automobile Testing & Research Institute (KATRI), serves as a pivotal second-phase testbed, offering a realistic traffic environment for pre-deployment safety assessments of AV technologies and services.

To bolster its capabilities, K-City is undergoing significant enhancements aimed at supporting Level 4 cooperative autonomous driving research. These improvements include the integration of advanced object detection systems (e.g., AI-driven cameras and LiDAR), deployment of Multi-access Edge Computing (MEC) and edge Roadside Units (RSUs) for real-time data processing, and the establishment of a centralized control center facilitating cloud-based resource management and comprehensive 3D monitoring.

Additionally, the development of a Vehicle-In-the-Loop Simulation (VILS) system is underway, enabling the fusion of virtual scenarios with physical vehicle testing. This system connects roadside equipment, onboard devices, and in-vehicle simulators to recreate complex traffic situations, including rare edge cases, thereby enhancing the robustness of AV evaluations. A suite of 52 test scenarios encompassing autonomous and cooperative driving has been crafted, featuring automated execution, outcome analysis, and issue tracking functionalities.

To streamline the testing process, K-City is implementing a user-friendly graphical interface that oversees scenario management, test execution, and result analysis. This platform ensures effective compatibility assessments between AVs and infrastructure, supports the selection of key performance indicators (KPIs), and facilitates prompt reporting.

Through these strategic advancements, K-City aims to solidify its position as a critical component within NATM's structured testing ecosystem, providing a comprehensive environment for validating the safety and reliability of Level 4 and higher autonomous driving technologies. Furthermore, by aligning with international standards and fostering global collaborations, K-City aspires to emerge as a leading testbed in the worldwide autonomous vehicle landscape.

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# 실도로 기반 객체 검지 데이터를 활용한 자율주행 시뮬레이션 시나리오 생성 및 검증 프레임워크 연구

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# A Simulation Scenario Generation and Validation Framework for CAVs Using Real-World Object Detection Data

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**Key Words :** Simulation-Based Validation(시뮬레이션 기반 검증), Scenario Generation(시나리오 생성), Edge Case(엣지 케이스), Risk Assessment(위험도 평가), Naturalistic Driving Environment(NDE, 실도로 교통환경)

## ABSTRACT

To ensure the safe and reliable development of Cooperative Autonomous Vehicles (CAVs), extensive testing and validation under diverse and rare scenarios is essential. However, real-world testing on public roads is costly and time-consuming. As an alternative, simulation-based testing offers cost-efficiency while enabling scalable and repeatable evaluation of critical driving scenarios, including edge cases that rarely occur in natural settings. This study proposes a comprehensive simulation validation framework that generates realistic traffic scenarios using real-world data collected from intelligent infrastructure, including AI-based LiDAR and camera systems.

We introduce a Naturalistic Driving Environment (NDE)-based pipeline that extracts time-series trajectory data, object metadata, and traffic signal information to build simulation-ready scenarios. These scenarios are converted into standard formats such as OpenScenario, allowing seamless integration with virtual and physical testing platforms. High-resolution video data (FHD at 30 fps) is used to capture fast-moving dynamic objects, ensuring accurate detection near conflict zones.

The proposed framework supports automatic risk assessment using surrogate safety metrics and conflict probability analysis. Risk levels are defined (e.g., Risk Level 1 to 3) to simulate increasing complexity—from safe intersection crossings to high-risk pedestrian interactions. The system enables iterative testing under identical conditions, supporting consistent benchmarking of decision-making algorithms in CAVs.

Finally, the framework includes a trajectory-to-scenario conversion module to bridge the gap between real-world observational data and simulation. This approach addresses the long-tail problem by generating diverse edge-case datasets, accelerating the evaluation and improvement of autonomous driving functions. The proposed methodology aims to enhance scenario realism, variability, and coverage across different Operational Design Domains (ODDs), contributing to safer and more robust autonomous vehicle technologies.

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# 버추얼크래시 기반 차량충돌 후 차량 거동과 손상 신뢰도 분석

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# Analysis of Post-Collision Vehicle Behavior and Damage Reliability Based on Virtual Crash

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**Key Words :** Virtual Crash(버추얼 크래시), Traffic Accident Reconstruction(교통사고 재현), Vehicle Damage Modeling(차량 파손 모델링), Post-Collision Vehicle Behavior(충돌 후 차량 거동)

## ABSTRACT

A precise analysis of post-collision vehicle motion and damage is essential for traffic accident reconstruction, offering insights into causes and responsibilities. Traditional tools like PC-Crash provide reliable kinematic simulations but have limitations in modeling structural deformations that influence post-impact trajectories. Virtual Crash addresses these by incorporating advanced damage progression models, enabling comprehensive accident simulations. This study proposes an approach to reconstruct accidents using Virtual Crash, focusing on vehicle kinematics and collision-induced deformation. Various scenarios—frontal, side, and rear-end impacts—were simulated by adjusting impact angle, velocity, and contact points. Key indicators including trajectories, speed, acceleration, and vehicle deformation were analyzed. To evaluate the reliability of Virtual Crash, results were compared with PC-Crash data, focusing on movement distance and rotation angles. Error rates were calculated to assess consistency. This research examines the relationship between vehicle damage and post-collision dynamics through simulation, exploring how structural changes influence motion and enhancing Virtual Crash's reliability. By improving analysis credibility, this study supports accurate scene investigations, causality determination, and development of effective traffic safety measures. Ultimately, the research advances collision analysis techniques, contributing to more precise and reliable accident reconstructions in both academic and practical fields.

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# Type 4 수소저장용기 시험별 유한요소해석 프로세스 설계

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# Design of Finite Element Analysis Processes for Type 4 Hydrogen Storage Vessel by Test Type

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**Key Words :** Hydrogen storage vessel(수소저장용기), Processes design(프로세스 설계), Time reduction(시간 절감), Safety evaluation(안전성 평가), FEA(유한요소해석)

## ABSTRACT

고압의 환경에서 사용되는 수소저장용기는 가스 누출에 의한 폭발 등의 대형 사고를 유발할 수 있기에 각국에서 정해 놓은 규정들을 토대로 충분한 안전성 검증이 이루어진 재료만을 이용하여 제조하며, 해당 공정에서의 검증 절차와 제조 후의 다양한 안전성 시험 절차들을 거치면서 안전성을 확보하고 있다. 이에 따라, 수소저장용기의 안전성 향상을 목적으로 하는 연구와 비용 절감을 위한 연구들이 주요국 및 각국의 기업에서 진행되고 있으나 실제 시험을 하는데 있어 시간과 비용이 많이 소모되고 있는 실정이다. 이를 위해, 본 연구에서는 유한요소해석을 활용하여 파열 압력 시험, 방향별 하중 시험, 충격 및 낙하 시험 등의 조건을 모사하고 안전성을 평가할 수 있는 프로세스를 설계함으로써 제품 개발에 소모되는 시간과 비용을 절감할 수 있는 결과와 개발 시의 기초 자료로써 활용될 수 있는 결과를 도출하고자 하였다.

본 연구는 산업통상자원부(MOTIE)와 한국산업기술평가관리원(KEIT)의 “소재부품기술개발사업”의 지원을 받아 연구한 과제입니다. (No. 20022511).
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# 비금속 Flexible 수소 배관용 접속재 안전성 평가

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# Structural Safety Evaluation of Connector for Non-metal Flexible Hydrogen Pipe

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**Key Words :** Hydrogen(수소), Pipe(배관), Time reduction(시간 절감), Safety evaluation(안전성 평가), FEA(유한요소해석)

## ABSTRACT

유럽, 미국 등 주요국에서 수소 활용의 비약적 확산을 위해 대량의 저렴한 수소 생산, 수요, 공급 연결체계, 도로운송 체계, 기술 및 제도적 수용 등 전주기 인프라 구축을 강화하고 있으며, 국내 2050 탄소중립 범부처 전략회의에서 수소 경제의 새로운 유망산업 육성 및 도시 국토의 탄소중립 전환의 중요성이 강조되고 있는 추세이다. 이에 따라, 지속 가능한 수소 활용을 위한 생산 방식별 중장기 공급인프라 구축 방안 마련이 필요한 상황이며, 주거 지역의 수소 공급을 위해 배관만으로 공급이 가능한 방안이 필요한 상황이다. 이를 위한 비금속 Flexible 배관은 기존 강관 배관과 달리 접속 개소 감소가 가능함에 따라 시공 시간 및 비용을 절감할 수 있다는 장점이 존재하나, 배관 균열에 따른 가스 누출 및 폭발에 대한 위험성이 있기에 안전성 확보를 위한 수소 배관용 접속재의 기술 개발이 필요한 실정이다. 이를 위해, 본 연구에서는 수소 배관용 접속재에 대한 안전성 시험들을 유한요소해석을 활용하여 평가할 수 있는 프로세스를 설계하고, 분석함으로써 향후 시험뿐만 아니라 조립 및 사용 조건에서의 구조적 안전성을 평가할 수 있는 토대를 마련하고자 하였다. 이에 따라, 수소 배관용 접속재의 조립 및 사용 조건 등을 유한요소해석으로 모사하고자 상용 구조해석 소프트웨어인 ABAQUS를 활용하여 유한요소해석 모델을 구축하였고, 실 조건과 동일한 경계 조건을 모사함으로써 해당 조건에서의 구조적 성능 및 안전성을 평가하였다. 이와 같은 일련의 프로세스를 설계하고 안전성을 평가함으로써 수소 배관용 접속재에 대한 성능을 평가할 수 있는 기반을 마련하였고, 개발 시의 시간 및 비용을 절감할 수 있는 결과를 도출하였다.

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# Type 4 수소저장용기용 고정장치의 구조 안전성 평가

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# Structural Safety Evaluation of Mount Block for Type 4 Hydrogen Storage Vessel

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**Key Words :** Hydrogen(수소), Transport(이송), Mount block(고정 장치), Safety evaluation(안전성 평가), FEA(유한요소해석)

## ABSTRACT

주요국에서 신재생에너지인 수소에너지를 활용한 연구가 증가하고 있는 추세이며, 이 중 수소의 저장 및 이송 측면에서 항공 및 철강뿐만 아니라 자동차 산업에서도 핵심 기술 중 하나로써 인식되고 있다. 이에 따라, 수소 저장 및 이송에 활용되는 수소저장용기의 안전성 향상을 위한 연구개발이 활발하게 이루어지고 있으나, 이송 시의 수소저장용기를 고정하는 고정장치에 관한 연구는 미비한 실정이다. 이를 위해, 본 연구에서는 상용 구조해석 소프트웨어인 ABAQUS를 활용하여 Type 4 수소저장용기용 고정장치에 대한 유한요소해석 모델 구성 및 안전성 평가 프로세스를 설계하였고, 이를 기반으로 선진사 제품 분석 및 사용 조건에서의 거동 및 안전성을 평가하였다. 또한, 분석한 결과를 기반으로 하여 개선 설계를 수행하였으며, 기존 모델 대비 강도, 강성, 무게 효율이 향상된 결과를 도출하였다. 이와 같은 일련의 결과들을 토대로 개발 제품에 대한 방향성을 제시할 수 있으며, 다양한 고정장치 개발에 있어 기초자료로써 활용될 수 있는 결과를 도출하였다.

본 연구는 산업통상자원부(MOTIE)와 한국산업기술평가관리원(KEIT)의 “소재부품기술개발사업”의 지원을 받아 연구한 과제입니다. (No. 20022511)
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# 농업용 다목적 전기차 프레임의 구조 해석 및 안전성 평가

김종호*

# Structural Analysis and Safety Evaluation of a Multi-Purpose Electric Vehicle Frame for Agricultural Use

Jong Ho Kim*

**Key Words :** Agricultural Multi-Purpose electric vehicle(농업용 다목적 전기차), Safety Evaluation(안전성 평가), Finite element analysis(유한 요소 해석)

## ABSTRACT

This study focuses on the structural analysis and safety evaluation of a frame used in a multi-purpose electric vehicle designed for agricultural environments. These vehicles are frequently subjected to heavy loads, rough terrain, and repetitive operational stresses, requiring robust structural integrity to ensure safe and reliable performance. A three-dimensional CAD model of the frame was developed, and static structural analysis was conducted using finite element analysis (FEA) tools. The analysis simulated realistic loading conditions derived from typical agricultural operations, including vertical impacts from road bumps, forward loads due to sudden braking, and lateral loads from curb strikes. These scenarios were modeled to reflect critical stress conditions that the frame may encounter during actual usage. The simulation results revealed significant stress concentrations and deformation in specific areas of the frame. Notably, high stress was observed around the cylinder mounting regions, rear brackets, and shock absorber connection points. These findings indicate structural vulnerabilities that could affect the safety and durability of the vehicle, especially under extreme operating conditions. By identifying these weak points through simulation, the study provides a foundation for future structural improvements and highlights areas that require design reinforcement. The research emphasizes the importance of early-stage structural evaluation in vehicle development, particularly for utility vehicles operating in high-load, off-road environments. The results serve as a valuable reference for manufacturers and engineers aiming to enhance the structural reliability and safety of electric vehicles for agricultural use. This approach supports efficient development and ensures that such vehicles can operate safely and effectively in the demanding conditions of agricultural fields.

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# 고정 객체의 밀도에 따른 LiDAR 정합 성능 비교 분석

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# Comparative Evaluation of LiDAR Registration Performance under Varying Fixed Object Densities

Hyungkyu Kim*, Seryong Baek**, Dongmin Choi**, Cheonho Kim***

**Key Words :** LiDAR(라이다), Point Cloud Registration(점군 정합), Fixed Object Density(고정 객체 밀도), Localization Accuracy(위치 정합 정확도), Autonomous Vehicles(자율주행차)

## ABSTRACT

Autonomous vehicles predominantly depend on GPS signals for localization. However, in environments where GPS reception is limited, such as tunnels, underground parking facilities, and urban canyons, this reliance often compromises positioning accuracy. To mitigate these limitations, researchers are increasingly investigating point cloud registration based on LiDAR as a complementary localization method. This study examines the influence of fixed structure density, such as walls, curbs, and signposts, on the effectiveness of LiDAR point cloud registration. Data collected by the company's data acquisition vehicle in various driving environments were used to analyze segments with differing levels of fixed object density. Density levels were classified by estimating the quantity of fixed structures in each LiDAR frame and selecting sequences that exhibited clearly distinguishable density characteristics. Point cloud registration between consecutive frames was performed using the ICP algorithm, with registration accuracy assessed through the calculation of RMSE between aligned point clouds. The results showed that higher fixed object density tended to correlate with reduced registration error and improved alignment stability. Quantitative analysis confirmed the potential impact of environmental structure on registration performance. These findings highlight LiDAR point cloud registration as a viable supplement to GPS in autonomous driving systems and suggest that defining ROI zones around static structures could enhance localization reliability.

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# 자율주행 차량 인지 성능평가를 위한 AI 기반 차량 탑재형 평가장치 개발

문성철* · 서주영** · 임재원* · 김인수*** · 박재홍****

# Development of an AI-Based Vehicle-Mounted Evaluation System for Autonomous Driving Perception Performance Assessment

Sungchul Moon*, Juyeong Seo**, Jaewon Lim*, Insu Kim***, Jaehong Park****

**Key Words :** Autonomous driving(자율주행), Object detect(객체 인지), Perception performance evaluation(인지 성능 평가), Sensor fusion(센서 융합), Deep learning(딥러닝)

## ABSTRACT

Real-time evaluation of autonomous vehicle perception is challenging due to environmental complexity and technical limitations. Additionally, deploying separate evaluation devices for different perception systems is economically inefficient. To address this issue, we propose an AI-based vehicle-mounted evaluation system for assessing autonomous perception performance. The proposed system performs model-based LiDAR and camera object detection, then fuses the data to generate ground truth. The system then compares the evaluation target's perception results with the ground truth and utilizes server communication to collect, analyze, and generate automated reports in real-time. This approach enables efficient and quantitative assessment of autonomous perception performance. Our proposed system enhances both economic feasibility and evaluation efficiency. Future work will explore its applicability in assessing ADAS and various perception models.

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# 보행자 교통사고에서의 역과(Dragging) 사고 분석

박지영* · 전혁진** · 이희영*** · 육현****

# Injury Analysis of Dragging-Type in Pedestrian Traffic Accidents

Ji Yeong Park*, Hyuk Jin Jeon**, Hee Young Lee***, Hyun Youk****

**Key Words :** Pedestrian(보행자), Traffic Accident(교통사고), Dragging(역과), Collision type(충돌유형)

## ABSTRACT

**Introduction:** Pedestrian fatalities are still high, especially including dragging-type accidents causing severe injuries. This study analyzes the severity and mortality rates of overall pedestrian traffic accidents (PTAs) and the subset of dragging-type accidents.

**Methods:** This study included PTA patients admitted to a regional emergency medical center over 23 months (May 2023–March 2025). Data on patient demographics, injury severity, and accident specifics were collected using ISS, KTAS, EMR, PACS, and emergency records. On-site investigations provided environmental and vehicle data, categorized into patient, accident, environment, and vehicle indicators.

**Results:** Among 140 PTA cases, the mean age was 57.6 years old (±24.1), with the highest incidence in individuals aged 65–80 years old (37.9%). Discharge outcomes were ER discharge (12.1%), general ward admission (31.4%), ICU admission (40.0%), and death (16.4%). KTAS levels were 1 (27.1%), 2 (43.6%), and 3 (27.9%). ISS 16≤ occurred in 41.4%, with a mean ISS of 17.6 (±15.5). Among 31 dragging-type cases, the mean age was 53.9 years old (±27.5), with the highest incidence in individuals aged 35–64 years old (35.5%). Discharge outcomes were ER discharge (12.9%), general ward admission (32.3%), ICU admission (38.7%), and death (16.1%). KTAS levels were 1 (29.0%), 2 (48.4%), and 3 (19.4%). ISS 16≤ occurred in 41.9%, with a mean ISS of 18 (±16.5%). Compared to all PTAs, injuries from dragging-type accidents occurred less frequently in the head & spine but more frequently in the thorax, abdomen, and lower extremities.

**Conclusion:** Dragging-type accidents were most frequent in 35–64 years old and had a higher incidence in KTAS 1–2 levels. In AIS by site, thorax, abdomen, and lower extremity injuries were more frequent. Preventive measures are needed to reduce injury severity in dragging accidents. The small sample size is a limitation of this study, and further in-depth injury analysis is necessary.

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# 전기차안전성평가기술 최적화 방안연구

박진석* · 이재웅** · 하성용**

# Study on Optimization of Electric Vehicle Safety Assessment Technology

Jinseok Park*, Jaewoong Lee**, Sungyong Ha**

**Key Words :** Electric vehicle(전기자동차), Battery(배터리), Safety(안전성), Driving Stability(주행 안정성), Education (교육)

## ABSTRACT

The purpose of this study is to develop safety standards and certification systems for the production safety of electric vehicles, to develop electric vehicle safety standards and evaluation technologies at the production stage, to establish a battery safety confirmation evaluation environment, and to develop evaluation technologies, and to optimize the development of inspection equipment and inspection technologies for the operation safety of electric vehicles. In particular, through the development of specialized human resources training and education systems for electric vehicle management business operators, the purpose is to develop Level 1, 2, and 3 education programs through the 1st and 2nd (advanced) demonstration education of electric vehicle technology experts, and to develop technologies for institutionalizing the management system and education system for electric vehicle management business operators.

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# 최적 제어 할당을 이용한 자율주행 차량 횡 방향 충돌 회피

박진용* · 최서연* · 우승훈***

# Autonomous Vehicle Lateral Collision Avoidance Using Optimal Control Allocation

Jinyong Park*, Seoyeon Choi*, Seunghoon Woo**

**Key Words :** Autonomous Vehicle(자율주행 차량), Collision Avoidance(충돌 회피), Optimal Control Allocation(최적 제어 할당), Chassis Integrated Control(샤시통합제어)

## ABSTRACT

As autonomous driving technology advances, vehicles have to make and respond to their own decisions in various driving environments, thereby highlighting the importance of collision avoidance. Quick and accurate responses are essential in unexpected situations such as the emergence of obstacles ahead or sudden lane changes. However, traditional avoidance methods based on front-wheel steering have limitations, especially in high-speed driving or in limited space. Therefore, coordinated control using multiple actuators is required.

With the advancement of the chassis system, rear wheel steering and ESC-based individual wheel braking are possible to achieve optimized collision avoidance. In this study, we propose to apply the optimal control assignment technique to improve path tracking performance during rapid avoidance maneuvers by utilizing rear wheel steering and individual wheel braking. The goal is to ensure stable collision avoidance by considering yaw rate, lateral slip angle, and path change.

The proposed algorithm consists of path generation, upper control, and lower control. Using the load preview sensor data, an avoidance path based on a third-order polynomial spline is generated. The system determines whether to avoid emergency braking or steering based on information on the speed and distance to obstacles. In the upper control, longitudinal and lateral tire forces are derived from feedback controls on yaw rates, lateral slip angles, and path deviations based on a two-freedom bicycle model. In the lower control, these forces are converted to actuator commands to optimize front and rear wheel steering angles and individual wheel braking forces. In addition, the actuator control weights are dynamically adjusted for curvature, yaw rate, and slip angles.

The verification was carried out by Model-in-the-Loop Simulation (MiLS) using Matlab/Simulink and CarMaker. As a result of testing the algorithm under various speed conditions, including rear collision and cut-in scenarios, it was confirmed that driving stability through collision avoidance is improved.

This research was conducted with the support of the Korea Institute for Advancement of Technology (KIAT) under the funding of the Ministry of Trade, Industry, and Energy (MOTIE) of the Republic of Korea in 2025.

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# Prescan을 활용한 AEB 시뮬레이션에서 환경 요인에 따른 가상 카메라 센서 성능 저하 특성 연구

배지인* · 이연섭** · 한현서** · 박정우** · 김종혁*** · 전우정****

# A Study on the Performance Degradation Characteristics of Virtual Camera Sensors in AEB Simulation Using Prescan Under Various Environmental Factors

Jiin Bae*, Yeonsub Lee**, Hyunseo Han**, Jungwoo Park**, Jonghyuk Kim***, Woojeong Jeon****

**Key Words :** AEB(자동긴급제동장치), Prescan(차량 시뮬레이션 프로그램), Physics Based Camera(물리 기반 카메라), EuroNCAP, Object Detection(객체 인식)

## ABSTRACT

첨단 운전자 지원 시스템(ADAS)은 차량 안전성을 향상하고 사고를 예방하는 핵심 기술이다. 특히, 자동긴급제동장치(Autonomous Emergency Braking, AEB)는 차량 및 보행자와의 충돌을 방지하거나 피해를 줄이는 능동 안전 시스템으로, 센서의 객체 탐지 및 인식 정확도에 크게 의존하며 조명, 날씨, 장애물 등의 환경 요인에 영향을 받는다. Prescan은 Radar, LiDAR, 카메라 등 다양한 센서를 지원하며, 환경 요인에 따른 센서 성능을 평가하는 데 유용하다. 특히, Unreal Engine 기반 Physics Based Camera(PBC)는 실제 카메라의 동작 원리를 정밀하게 반영하는 고급 센서 모델로. 기존 OpenSceneGraph(OSG) 기반 Detailed Camera보다 조명, 반사, 렌즈 왜곡, 날씨 변화 등의 영향을 현실적으로 반영할 수 있어 더욱 정밀한 시뮬레이션 환경 구축이 가능하다. 본 연구에서는 EuroNCAP AEB Car-to-Car Rear Stationary(CCRs) 시나리오를 기반으로 주간 및 야간 강우 환경에서 Detailed Camera와 PBC의 성능을 비교하였다. 주요 성능 평가 지표로는 객체 최초 인식 시점 및 상대 거리, 전방 충돌 경고(Forward Collision Warning, FCW) TTC, 부분 제동(Partial Braking) TTC, 완전 제동(Full Braking) TTC를 설정하였다. 시뮬레이션 결과, 모든 시나리오에서 PBC는 Detailed Camera에 비해 객체 인식이 지연되는 경향을 보였다. 특히, 야간 강우 시나리오에서 PBC가 객체를 최초로 인식한 시점의 상대 거리가 57.9% 지연되었으며, 이는 가장 큰 지연폭으로 확인되었다. 또한, FCW TTC, Partial Braking TTC, Full Braking TTC가 모두 0.55초로 충돌이 발생하였다. 이는 PBC가 빗방울과 조명 등의 환경적 요인을 보다 현실적으로 반영함에 따라 객체 인식과 센서 퓨전 과정에서 지연이 발생하고, 결과적으로 AEB 시스템의 성능에도 영향을 미친다는 점을 시사한다. 향후 연구에서는 동일한 시나리오에서 실차 실험을 수행하고, 그 결과를 비교함으로써 PBC 기반 AEB 시뮬레이션의 신뢰성을 검증할 예정이다. 이를 통해 환경 요인에 따른 실제 ADAS 기능의 미작동 원인을 더욱 명확하게 규명할 수 있을 것으로 예상된다.

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# MORAI 시뮬레이터를 이용한 차량 충돌 직전(Pre-Crash) 상황 데이터 재현 및 신뢰성 평가 연구

송치원* · 전형석** · 백세룡*** · 이기범****,†

# Reproduction and Reliability Assessment of Pre-Crash Scenario Data Using the MORAI Simulator

Chiwon Song*, Hyeongseok Jeon**, Seryong Baek***, Kibeom Lee****,†

**Key Words :** Autonomous vehicle(자율주행차), Traffic accident(교통사고), Simulation(시뮬레이션)

## ABSTRACT

To develop autonomous vehicles, various environments and scenarios must be considered in the design and development process. Ensuring safety requires precise reproduction of real-world traffic accidents, forming a foundation for analyzing accident causes through simulation. Euro NCAP conducts simulations to assess vehicle safety by examining acceleration, trajectory, and dynamic characteristics. Compared to previous autonomous driving simulations, accident simulations demand higher accuracy, particularly in modeling pre-crash situations, which are crucial for evaluating vehicle safety technologies. By utilizing the MORAI Simulator, real-world accident scenarios were reproduced to assess its reliability and safety. Scenarios based on Euro NCAP data were implemented, and the generated data were compared with actual accident data. To evaluate accuracy, vehicle acceleration, trajectory, and dynamic characteristics were quantitatively analyzed using statistical methods such as correlation analysis, RMSE, and MAE. Particular emphasis was placed on how closely vehicle behavior before and after a collision matched the designed scenarios. This study demonstrates that the MORAI Simulator can serve as a reliable tool for predicting accidents and evaluating the safety of autonomous vehicles through the realistic and accurate reproduction of accident scenarios. The findings confirm that the simulator can be effectively utilized for recreating traffic accidents in a virtual environment.

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# 고속 전방 충돌 시 뒤보기 좌석 탑승자에 대한 인체 모델의 생체유사성 평가

안용진* · 박지호** · 김태웅***

# Evaluation of the Biofidelity of a Human Body Model for Rear-Facing Seat Occupants in High-Speed Frontal Crashes

Yongjin An*, Jiho Park**, Taewung Kim***

**Key Words :** Rear-facing seat(뒤보기 시트), Post-mortem human subjects(사후 인간 피험자), Human body model(인체 모델), Finite element(유한요소)

## ABSTRACT

With the advancement of autonomous driving technology, vehicle interiors and seat configurations are diversifying. In the future, front-row seats are expected to rotate 180 degrees to face the second row. In such configurations, high-speed frontal collisions may cause severe occupant injuries, necessitating research to mitigate these risks. Although post-mortem human subjects (PMHS) experiments have been conducted, the limited number of tests makes it difficult to secure sufficient data. To address this, human body models can be utilized as an alternative. However, it is essential to validate whether these models can accurately replicate occupant kinematics under such conditions. This study established a simulation environment using a human body model and verified its reliability by comparing simulation results with PMHS data. The seat and cockpit models were based on experimental products provided by the manufacturer, and precise positioning was achieved using angle and Vicon data. The same sled pulse from the experiments was applied in the frontal collision simulation. HIC(Head Injury Criterion) showed 1941 in the experiment and 3143 in the simulation, while chest maximum deflection in the simulation was about 4 mm greater, occurring 60 ms earlier. This study provides fundamental data for future research on frontal collision simulations involving rear-facing seat occupants using human body models.

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# ADAS 사고 분석을 위한 실차 실험 데이터 기반 ACC 기능 시뮬레이션에 관한 연구

이대현* · 이연섭** · 한현서** · 박정우** · 김종혁*** · 전우정****

# Real-Vehicle Data-Based ACC Function Simulation for ADAS Accident Analysis

Daehyeon Lee*, Yeonsub Lee**, Hyunseo Han**, Jungwoo Park**,
Jonghyuk Kim***, Woojeong Jeon****

**Key Words :** ACC(적응형 크루즈 컨트롤), ADAS(운전자 보조 시스템), Euro NCAP(유로 앤캡), C2C scenario(차대차 시나리오), Operational characteristics and system limitations(작동 및 한계 특성), Accident Simulation (사고 재현)

## ABSTRACT

ACC(Adaptive Cruise Control)는 차량의 속도를 자동으로 조절해 앞 차량과의 거리를 유지하는 기능으로 고속도로에서 운전자의 운전 편의성을 높여주고 있다. 그러나 한국도로공사에 따르면, 2020년부터 2024년 7월까지 고속도로에서 ACC 등 주행 보조 기능을 사용하는 중 발생한 교통사고는 총 19건에 달하며, 이로 인해 17명이 사망한 것으로 보고되었다. 특히 2024년 상반기에만 8건의 사고가 발생하였으며, 관련 사고가 최근 들어 더욱 빈번해지는 추세를 보이고 있다. 이러한 사고는 ACC시스템의 한계에 대한 충분한 인식 없이 기술을 맹신하는 행태와 관련이 깊다. 이에 따라, 실차 데이터를 기반으로 ACC 기능의 작동 조건, 특성, 그리고 시스템 한계를 정밀하게 분석하고, 이를 시뮬레이션을 통해 실제 주행 상황과 유사하게 재현할 수 있는 연구의 필요성이 점차 커지고 있다. 본 연구는 Euro NCAP의 Assisted Driving Test v2.2에 기반한 C2C(Car-to-Car) 시나리오를 적용하여 실차 실험을 수행하고, 이를 활용한 ACC 시뮬레이션을 통해 시스템의 작동 특성과 한계 조건을 정량적으로 분석하며, 실차 실험과 비교하여 그 타당성을 검증하는 것을 목적으로 한다. 시뮬레이션에는 Simulink와 Siemens사의 Prescan을 활용하였으며, 실차 실험을 통해 수집된 감가속도, 타겟 차량과의 overlap 정보를 기반으로 ACC 제어 로직을 구현하였다. CCRs(Car-to-Car Rear stationary) 상황에서의 실차 데이터 분석 결과, VUT(Vehicle Under Test)는 최대 감속도까지 선형적으로 감속이 증가한 후, 다시 선형적으로 감속도가 감소하면서 타겟 차량과의 거리가 약 4m에 도달하는 시점에서 정지한 결과를 보였다. 이러한 실차의 감속 특성을 재현하기 위해 제어 로직을 구성하였다. 이러한 로직 설계를 통한 시뮬레이션 결과는 실차 실험 데이터와 높은 정량적 유사성을 보였으며, ACC의 작동 특성과 한계 조건을 정밀하게 재현할 수 있음을 확인하였다. 향후에는 CCRs뿐만 아니라 Euro NCAP에서 정의된 다양한 시나리오에서 정밀하게 재현할 수 있는 통합 시뮬레이션 플랫폼을 구축할 계획이다. 이를 통해 ACC 관련 실제 사고의 재현 및 원인 분석이 가능해지고, 위험 조건에서의 시스템 한계와 반응 특성을 사전에 분석할 수 있을 것으로 예상된다.

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# VILS 기반 악조건 환경 구현을 통한 AEB 시스템 성능 검증 연구

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# A Study on the Performance Verification of AEB Systems through VILS-Based Adverse Conditions

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**Key Words :** Adverse Conditions(악조건 환경), VILS(차량 기반 루프 시뮬레이션), AEB(자동 긴급 제동 시스템), camera sensor(카메라 센서), Autonoumos Vehicle(자율주행차)

## ABSTRACT

The Autonomous Emergency Braking (AEB) system, one of the core safety functions in autonomous vehicles, relies primarily on camera-based object detection. Its operational reliability can be critically compromised under adverse environmental conditions, such as sensor contamination or failure. To safely reproduce sensor fault scenarios that are difficult to simulate in real road environments, this study utilizes a Vehicle-in-the-Loop Simulation (VILS) platform to quantitatively analyze the degradation of AEB perception performance. Various adverse condition scenarios—such as lens contamination, lens damage, and camera failure—were defined, and key performance metrics including AEB activation rate, collision occurrence, and reaction time were measured under each condition. The test setup involved equipment such as a steering robot, DGPS-based RT system, and soft target to simulate diverse fault scenarios. This study quantitatively verifies the performance variations of the AEB system under sensor contamination and fault conditions using VILS, and is expected to provide foundational data for establishing sensor fault response strategies and enhancing functional safety in autonomous vehicles.

Figure 1. Examples of Camera Sensor Contamination and Failure Scenarios in Road Environments (Dust, Lens Damage, Camera Malfunction)

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# Adaptive Cruise Control의 작동 특성 및 한계에 관한 실험적 연구

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# Experimental Study on the Operating Characteristics and Limitations of Adaptive Cruise Control

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**Key Words :** Adaptive cruise control(적응형 크루즈 컨트롤), Deceleration trend(감속 경향), Time gap(시간 간격), Vehicel recognition(차량 인식), EuroNCAP(유로앤캡)

## ABSTRACT

ADAS(Advanced Driver Assistance System) 기술의 발전으로 운전자의 부담이 줄어든 반면, 해당 기능을 맹신하여 운전에 집중하지 않는 사례가 증가하고 있다. 특히, 고속도로에서 ADAS 기능 중 ACC(Adaptive Cruise Control) 관련 사고 발생 건수 또한 매년 증가하는 추세이다. 이러한 사고를 분석하기 위해선 ACC 기능의 작동 특성과 한계를 정확히 이해하는 것이 중요하다. 본 연구에서는 실차 실험을 진행하여 ACC의 감속 경향, Time Gap 특성 및 차량 인식 성능을 분석하였다. 실험 차량으로는 기아 쏘렌토 MQ4 2024년식 모델을 사용하였으며, 실험 환경은 EuroNCAP CCRs(Car To Car, Rear, stationary target) 시험 절차를 기반으로 설정하였다. 분석 결과, 속도가 증가할수록 브레이크 압력이 강하게 작용하였으며, 감속도의 기울기는 속도가 높을수록 가파르게 변화하는 경향을 보였다. 차량 인식 측면에서는 30~80 km/h 구간에서 정상적으로 인식 및 ACC 감속이 이루어졌으나, 85 km/h 이상에서는 차량 인식 실패가 발생하였다. 이로 인해 AEB가 작동했음에도 불구하고 충돌이 발생하였다. Time Gap은 차량을 인식하는 구간에서는 속도가 증가할수록 점차 감소하는 경향을 보였으나, 제동과 관련된 뚜렷한 경향은 나타나지 않았다. 또한, ACC 레벨에 따른 감속 특성, 정차 시 유지되는 거리 및 차량 인식 성능은 유사한 결과를 확인하였다. 이를 통해, ACC 시스템은 속도 변화에 따라 감속 및 차량 인식 특성이 달라지며, 특정 속도 이상에서는 차량 인식 지연 및 제동 성능의 한계로 인해 안전성 저하와 사고 위험이 증가할 가능성이 있음을 확인하였다. 또한, CCRs 상황에서 ACC 레벨에 따른 작동 특성은 유사한 것으로 분석되었다. 향후 연구에서는 ACC Level에 따른 작동 특성 차이를 비교 분석하기 위해 CCRm(Car To Car, Rear, moving target) 시험을 추가적으로 분석할 예정이다. 또한, 다양한 주행 환경에서 ACC와 AEB 전환의 통합적인 감속 패턴과 한계점을 심층적으로 연구할 계획이다.

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# 자율주행 차량용 Fail-Operational 인지 모듈 구현

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# Implementation of a Fail-Operational Perception Module for Autonomous Driving

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**Key Words :** Fail-operational(고장 허용 제어), Autonomous driving(자율 주행), Perception module(인지 모듈), Sensor fusion(센서 퓨전)

## ABSTRACT

This paper presents the design and implementation of a fail-operational perception module for autonomous vehicles, utilizing an NVIDIA Orin platform and our board dedicated to perception tasks. The Orin board processes real-time detections from radar and LiDAR sensors, receives GPS signals, and transmits the preprocessed data via a custom communication protocol over ethernet. A separate perception board then integrates this multi-sensor input—alongside camera-based lane and object detection results—using sensor fusion algorithms, thereby achieving robust perception performance. By effectively combining data from radar, LiDAR, GPS, and camera feeds, the system reduces false positives and enhances lane recognition stability. The fused perception data is subsequently forwarded to a decision-making unit, where fail-operational strategies—such as redundancy and fault-tolerant protocols—ensure continuous autonomous driving even under potential sensor malfunctions. Future work will focus on optimizing the sensor fus부ion algorithm for high-speed driving scenarios and strengthening fail-operational mechanisms for adverse weather conditions. These efforts aim to establish a more resilient and efficient perception framework, ultimately enhancing the safety and reliability of autonomous driving systems.

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# Type 4 수소저장용기의 축소 시제를 활용한 가속화 시험 평가의 해석적 검증 연구

정경현* · 김한상**,†

# Analytical Verification Study of Accelerated Test Using Scale Model of Type 4 Hydrogen Storage Vessels

Kyung Hyun Chung*, Han Sang Kim**,†

**Key Words :** Hydrogen(수소), Ansys-CFX(유동해석 소프트웨어), ABAQUS(구조해석 소프트웨어), Scale Model(축소 시제), FSI-Analysis Method(유동-구조 연성 해석 방법론)

## ABSTRACT

고압 수소저장용기가 상용화된 현재, 에너지 밀도가 높지 않은 고압 저장 방식의 수소저장용기는 주행 거리를 늘리기 위하여 용기의 대형화가 필수적이다. 이에 따라 수소전기 상용차, 상용차용 고압 수소저장용기의 상용화 및 개발이 진행되었고, 수요 또한 크게 증가하였다. 따라서, 대용량 고압 수소저장용기의 가스 반복 시험의 비용을 절감하고자 축소 시제를 활용한 시험 평가 방법을 해석적으로 검증하였다. Ansys-CFX를 활용하여 유동 해석을 수행하였고, ABAUQ를 활용하여 열전달 해석 및 구조해석을 수행하였다. ABAQUS WCM을 활용하여 수소저장용기 복합재료부를 설계하였으며, 파열압 시험 모사 해석을 통해 와인딩 패턴 및 설계의 안전성을 확인하였다. CFX의 유동 해석 결과를 ABAQUS 수소저장용기 모델에 Mapping 하여 충전 완료 시점에서의 용기 온도 분포를 얻어내었고, 해당 결과와 내압을 적용하여 충전 상황에서 압력과 온도 변화에 의해 용기에 가해지는 응력의 분포를 활용하였다. 본 연구에서는 축소 시제를 활용한 가스 반복 시험의 신뢰성을 해석적으로 검증하였으며, Ansys-CFX와 ABAQUS를 활용한 수소저장용기 충전 상황 모사 해석의 방법론을 제시하였다.

본 연구는 산업통상자원부(MOTIE)와 한국산업기술기획평가관리원의 “소재부품기술개발사업”의 지원을 받아 연구한 과제입니다.(No. 20022511)
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# Skid-Steering 기반 모바일 로봇의 경로 추종 성능 비교를 위한 MPC 제어기 설계에 관한 연구

정윤모* · 신형주** · 정재일**

# Design of an MPC Controller for Path Following Performance Comparsion of a Skid-Steering Mobile Robots

Yoonmo Jeong*, Hyungju Shin**, Jayil Jeong**

**Key Words :** MPC(모델 예측 제어), PID(비례-적분-미분 제어), Skid-Steering(미끄럼 조향), Mobile Robot(이동 로봇)

## ABSTRACT

In this study, a Model Predictive Controller (MPC) was designed for a skid-steering mobile robot developed for automated vehicle safety testing, and its path-following performance was compared with that of a conventional PID controller. A simplified linear system model was derived by linearizing the original nonlinear dynamics of the skid-steering mobile robot. Based on this linear model, a cost function tailored for path-following was formulated, along with relevant constraints. The designed MPC controller was then tested in simulation environments using Simulink and CarMaker, focusing on two representative highway driving scenarios: straight driving and lane-cut-in maneuvers. The path-following error and target speed tracking performance of the MPC controller were compared with those of the PID controller. The results demonstrated the effectiveness of the MPC approach and highlighted key factors that should be considered to improve path-following performance in skid-steering mobile robots. This study confirms the potential of MPC in enhancing the stability and accuracy of mobile robot based on skid-steering platforms.

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# 자율주행차 추돌 사고유형에 대한 사고조사 프로세스 개발

조수한* · 강민재* · 박종진**

# Development of Accident Investigation Process for Autonomous Vehicle Rear-End Collisions

Suhan Cho*, Minjae Kang*, Jongjin Park**

**Key Words :** Traffic accident(교통사고), Accident investigation process(사고조사프로세스), DMV(차량관리국), Rear-end collision(후방추돌), Autonomous vehicle(자율주행차), V2X(차량-사물통신)

## ABSTRACT

As part of the Autonomous Driving Technology Development Innovation Program, the Autonomous Driving Living Lab is conducting pilot operations of AV(Autonomous Vehicle) in K-City (Autonomous Driving Test City). Infrastructure is being built to simulate various road environments. As AV become commercialized, Analyzing new causes of traffic accident will be needed, and responsibility for accident must be clarified. According to data from the California Department of Motor Vehicles (DMV), rear-end collisions account for 41.31% of AV accidents. Phantom braking, caused by sensor error or system failure, leads to sudden braking and unnecessary deceleration, increasing rear-end collision risk. Additionally, in traffic environment where autonomous and conventional vehicles coexist, human drivers' predictive behavior may also contribute to accidents.

In this study, we developed an accident investigation process for rear-end collisions in AV. The existing procedure for conventional vehicles was expanded, focusing on four major categories: human factors, vehicle factors, road environment factors, and V2X(Vehicle-to-Everything) factors. Human factors examine the role of drivers and passengers in levels 3 or 4 of autonomous driving. Vehicle factors analyze core components of the autonomous system, such as perception, decision-making, and control. Road environment factors include various conditions, such as weather, road structure, lane, and pavement. V2X factors include network connectivity and communication with infrastructure, other vehicles, pedestrians. This classification helps adjust the investigation process to the anticipated cause, allowing flexible prioritization of the steps involved.

We plan to extend this process to include road-user collisions, head-on collisions, lane deviations, and intersection accidents. It may support investigation agencies to efficiently analyze the causes of AV traffic accidents and clarify liability.

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# 자율주행 자동차 안전성 평가 시나리오에서 타겟 로봇 간 거리 및 속도 제어를 위한 이중 루프 PID 알고리즘

조준성* · 정재일**

# Double-Loop PID Control for Inter-Robot Distance and Speed Regulation in Automated Vehicle Safety Evaluation Scenarios

Junseong Jo*, Jayil Jeong**

**Key Words :** Double-loop PID control(이중 루프 PID제어), Real-time GPS sensor data(GPS 센서 기반 실시간 데이터) Automated vehicle safety evaluation(자율주행 자동차 안전성 평가)

## ABSTRACT

This study proposes a Double-loop PID control algorithm for maintaining inter-robot distance and achieving target speeds in scenarios designed for automated vehicle safety evaluation. Each target robot is equipped with a GPS sensor to acquire real-time position and velocity data, and based on these data, the relative distance and speed differences between robots are precisely calculated. The inner control loop compensates for inter-robot distance errors, while the outer control loop adjusts the discrepancy between the target and actual speeds, ensuring that the robots maintain stable relative positions and adhere to a consistent speed profile that meets strict safety evaluation criteria. Simulation results confirm that the proposed algorithm effectively achieves the set target distance and speed, demonstrating its promising applicability in the field of automated vehicle safety evaluation.

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# 자율주행 3단계 검증 체계 구축 및 적용 방안

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# Development and Implementation of a Three-Stage Validation Framework for Autonomous Driving

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**Key Words :** NATM, Virtual(가상환경), Living Lab(리빙랩), K-City(케이시티)

## ABSTRACT

The Korean government has adopted the NATM (New Assessment Test Methodology) guidelines proposed by UNECE WP29 to validate autonomous driving systems. NATM is based on a three-stage validation framework consisting of virtual, physical, and real-world testing, forming a continuous cycle with regularly updated test scenarios.

Virtual Testing: A digital replica of the PG(proving ground) enables large-scale scenario testing in a simulation environment.

Physical Testing: Conducted at Korea's largest PG, incorporating mixed reality VILS testing, where virtual scenarios and objects are injected into the vehicle under test (VUT). A monitoring system oversees the process, utilizing a scenario editor to create, transmit, and analyze scenarios based on key performance indicators (KPIs).

Real-World Testing: A Living Lab with approximately 50 intersections integrates infrastructure sensors to monitor road events. Novel, atypical, or hazardous events are converted into test scenarios and re-evaluated in virtual and physical environments. Additionally, naturalistic driving data is collected and utilized for virtual testing.

In this paper, a structured three-stage validation framework for evaluating autonomous driving systems, ensuring a comprehensive and scalable testing methodology that can support future regulatory developments.

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# PC-Crash를 활용한 자율주행 차량 교통사고 시뮬레이션 데이터의 DSSAD 형식 자동 변환 시스템

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# Automatic Conversion System of Autonomous Vehicle Traffic Accident Simulation Data into DSSAD Format using PC-Crash

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**Key Words :** Traffic accident(교통사고), Database(데이터베이스), DSSAD(자율주행 정보 기록 장치), Traffic accident investigation(교통사고조사), PC-Crash(분석프로그램)

## ABSTRACT

According to SAE, the autonomous vehicle market is projected to grow at an annual average rate of 36.2% by 2025. Amid the rapid spread of autonomous vehicles, clearly identifying the cause of traffic accidents and determining liability has emerged as a critical challenge to ensure technological reliability and legal stability. In particular, the UNECE WP.29 regulation mandates the recording of data for 5 seconds before and after an accident through the Data Storage System for Automated Driving (DSSAD) to ensure the safety of autonomous vehicles. This is essential for swiftly and accurately analyzing accident data to determine legal responsibility and identify potential technical defects. Samsong Co., Ltd. has produced PC-Crash simulations for various traffic accidents, but converting this simulation data into the DSSAD format has proven to be time-consuming and costly. Therefore, this study aims to develop a system that automatically converts the physical vehicle data generated by the PC-Crash simulation software into the DSSAD standard format, thereby enhancing the efficiency of accident reconstruction and analysis. This system seeks to support the rapid identification of accident causes and liability in autonomous vehicle incidents, ultimately contributing to improving the reliability of autonomous driving technology.

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# PC-Crash 활용 사륜조향 및 스티어 바이 와이어 기술 적용 차량 거동에 관한 연구

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# A Study on Vehicle Dynamics with Steer-by-Wire Technology and Four-Wheel Steering Based on PC-Crash

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**Key Words :** Pc-crash(피씨크래쉬), Four-wheel steering(사륜조향), Steer-by-wire(스티어바이와이어), Crashreconstruction(사고재현)

## ABSTRACT

Four-Wheel Steering (4WS) systems and Steer-by-Wire technologies have recently been applied to high-end vehicles, enabling differentiated vehicle dynamics from conventional front-wheel steering systems. However, current traffic accident analysis programs basically simulate front-wheel steering, and it is inconvenient for users to input the rear-wheel steering angle manually when implementing a four-wheel steering system. Also, the steering wheel and steering gear are not mechanically connected in a steer-by-wire, so the steering gear ratio is not expected to be fixed but applied variably. However, PC-Crash currently sets the steering gear ratio to a fixed value, so the study aims to improve by adding code to apply variable gear ratios.

This study has developed a system that can apply variable ratio steering systems such as in-phase, counter-phase, and front-wheel steering under various driving conditions.

The developed system applies variable gear ratio steering based on Steer-by-Wire, overcoming the limitations caused by conventional fixed steering gear ratios. This enables more precise steering control in various driving conditions.

This study provides significant technical data that can contribute to steering control and collision analysis for future vehicles such as autonomous and electric vehicles.

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# 자율주행차량 평가용 타겟 로봇 알고리즘 검증을 위한 시뮬레이션 모델 개발

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# Development of a Simulation Model for Validating Target Robot Algorithms in Autonomated Vehicle Evaluation

Seunguk Hwang*, Jayil Jeong**

**Key Words :** Automated Vehicle(자율주행자동차), Simulation verification(시뮬레이션 검증)

## ABSTRACT

Scenario-based performance evaluation has become increasingly important with the advancement of automated driving technologies. To facilitate such evaluations without damaging the test vehicle, we employed a target robot equipped with a collision-safe car dummy. In this study, we modeled the target robot using CarMaker and MATLAB/Simulink, then validated its performance by comparing simulation results with real vehicle test data under identical conditions. The results demonstrated a close correlation between the simulated and experimental data, confirming the suitability of the proposed target robot model for scenario-based automated driving tests.

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