Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2025, 12(4):126-132

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Virtual Simulation and Analysis of Adaptive Cruise Control

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Abstract: Adaptive Cruise Control (ACC) systems are key components of modern intelligent transportation, designed to enhance driving comfort and safety by automatically adjusting vehicle speed to maintain a safe distance from preceding vehicles. This project focuses on the virtual simulation of an ACC system using a model-based development approach. A virtual environment is created to replicate real-world driving conditions, allowing for the design, testing, and validation of the ACC algorithms without the need for physical prototypes. The simulation models vehicle dynamics, sensor inputs, and environmental factors to evaluate the system's performance under various traffic scenarios, including cut-ins, sudden braking, and stop-and-go conditions. Results demonstrate that virtual simulation significantly accelerates development cycles, reduces costs, and improves system robustness before implementation in actual vehicles. The study highlights the critical role of simulation in advancing the reliability and effectiveness of autonomous driving technologies.

Keywords: Adaptive Cruise Control (ACC), Virtual Simulation, Vehicle Dynamics, Model-Based Development, Intelligent Transportation Systems, Autonomous Driving, Sensor Modeling.

1. Introduction

Adaptive Cruise Control (ACC) is an advanced system that builds upon traditional cruise control by automatically adjusting a vehicle's speed based on the traffic conditions ahead. In a traditional cruise control system, the driver sets a specific speed, and the system maintains that speed regardless of changes in traffic or road conditions.

Once the driver sets a desired speed, ACC actively monitors the distance between the vehicle and any car ahead. If the system detects a slower vehicle in the same lane, it will automatically reduce the car's speed to maintain a safe and pre-set following distance. This distance is typically adjustable, allowing drivers to choose how closely they want to follow the car ahead. If the vehicle in front accelerates or changes lanes, ACC will detect this and automatically increase the vehicle's speed to return to the preset speed.

The system provides a smooth, automated driving experience by dynamically adjusting speed without requiring the driver to manually brake or accelerate. In addition, ACC helps reduce the chances of rear-end collisions by ensuring that the vehicle maintains an appropriate following distance at all times. It's especially useful in heavy traffic or long highway drives, as it minimizes the driver's need to constantly adjust speed.

Overall, ACC enhances driving comfort and safety by providing automatic speed adjustment, improving overall traffic flow, and reducing fatigue on longer journeys. It is a key step toward more advanced driver-assistance systems, offering a smoother, more controlled driving experience with minimal driver input.

2. Literature Review

Adaptive Cruise Control (ACC) systems have evolved as a fundamental feature in modern vehicles, forming a bridge between traditional cruise control and fully autonomous driving. Early work by [6] Ioannou and Chien (1993) introduced ACC concepts focused on longitudinal vehicle control through basic radar-based detection systems. Since then, advancements in sensor technologies and control algorithms have significantly improved ACC performance.

Virtual simulation environments have become essential tools for ACC development, offering safer, faster, and more cost-effective alternatives to physical prototyping. Researchers like [10] Kuutti et al. (2018) highlighted the importance of simulation platforms in replicating complex, dynamic traffic scenarios critical for testing ACC behavior. Simulation tools such as MATLAB/Simulink, CarMaker, and PreScan have enabled the integration of realistic vehicle dynamics, sensor models, and driver behavior, thereby enhancing the fidelity of ACC system evaluations.

Control strategies for ACC vary widely in the literature. Conventional approaches rely on PID controllers, as explored by [2] Rajamani (2012), while more recent studies favor model predictive control (MPC) methods for better anticipation of future vehicle states ([1] Gao et al., 2016). Virtual testing has proven vital for assessing these control strategies across a range of environmental factors, such as varying road friction, sudden cut-ins by other vehicles, and sensor noise.

Moreover, the role of virtual validation has been emphasized in regulatory and standardization efforts. For instance, the UNECE regulations recommend extensive simulation-based validation to ensure safety under edge-case scenarios that are rare but critical.

Overall, the literature strongly supports the integration of virtual simulation in ACC system development, particularly for early-stage testing, system optimization, and safety validation. However, gaps remain in fully capturing unpredictable human behaviors and highly dynamic multi-agent interactions, motivating ongoing research into more sophisticated and scalable virtual environments.

Adaptive Cruise Control (ACC)

Adaptive Cruise Control (ACC) is an advanced driver-assistance system that automatically adjusts a vehicle's speed to maintain a safe distance from the car ahead. It uses sensors like radar and cameras to detect surrounding traffic. ACC improves driving comfort, reduces driver fatigue, and enhances road safety. Modern ACC systems are increasingly integrating predictive and cooperative features for better performance.

Software-in-the-Loop (SIL) simulation is a testing method where the control software is run on a virtual platform to validate its behavior without using real hardware. It helps developers check system performance, find bugs, and optimize algorithms early in the development cycle. SIL allows realistic testing by simulating vehicle dynamics, sensors, and the environment. This approach reduces development time and cost while improving system reliability.

An In-Vehicle Network (IVN) is a communication system within a vehicle that connects various electronic control units (ECUs) to enable data exchange and coordination between them. IVNs are crucial for modern vehicles, supporting functionalities like engine control, safety systems, entertainment, and autonomous driving features. Common protocols used in IVNs include Controller Area Network (CAN), Local Interconnect Network (LIN), and FlexRay. These networks ensure efficient data transfer and enable systems to work in harmony, improving vehicle performance, safety and user experience.

3. Proposed Methodology

The methodology for this project involves using Software-in-the-Loop (SIL) simulation to validate the functionality of the Adaptive cruise control (ACC), Transmission control module (TCM) in a simulated vehicle environment. The proposed approach combines real software with simulated components to mimic real-world operating conditions, enabling thorough testing of the vehicle’s control systems.

1. Hardware Setup

The hardware setup consists of the following components:

• **Transmission Control Module (TCM):** it is used to transmit the real time speed data of the vehicle which integrate with the other ECU’s for the simulation.

- **In Vehicle Network (IVN):** The IVN prototype is used for the real time data transmission and the data exchange like the real time work of the ECU.
- **Instrument Cluster (IC):** The IC will be connected to the IVN system to receive data from the TCM and other ECUs for displaying critical vehicle information.
- **Ultrasonic sensors:** The ultrasonic sensors are used to detect the distance between the object and the vehicle to set the speed limit in order to reduce the chances of the accidents.
- **CAN Interface:** A CAN interface will be used to simulate the vehicle's communication network, enabling data exchange between the TCM, IC and other ECUs.
- **TS Master:** The TS Master tool will be used for creating test scripts, automating test scenarios, and analyzing the results in real-time.

2. Simulation Environment

The SIL simulation environment will simulate the operation of various in-vehicle systems, including sensors, actuators, and other ECUs. The simulated environment will provide inputs, such as sensor data (speed, ACC status, break pedal condition) which will be sent to the TCM and IC to test their response under different operational conditions.

3. Test Scenarios

The project will include the following test scenarios:

- **Functional Testing:** Ensuring that the TCM and IC respond correctly to normal operating conditions, such as vehicle speed, acc status, set speed and real-time data display on the IC.
- **Emergency Condition Testing:** the emergency testing is whenever the sensor detect the object suddenly if the object is less than the described distance the emergency breakings should be applied.
- **Stress Testing:** Testing the system under extreme conditions, such as emergency breaking and sudden object detection or rapid changes in sensor data, to verify the robustness of the TCM and IC.

4. Automation and Analysis

Test cases will be automated using TS Master and CAPL scripting to simulate various driving scenarios and validate the interaction between the TCM, ACC, IC, and other ECUs. Data from the tests will be logged and analyzed to assess the performance, accuracy, and reliability of the systems.

5. Validation

The results of the simulation will be compared with the expected behavior of the TCM, ACC and IC systems. Any discrepancies will be analyzed, and further adjustments will be made to the simulation environment or hardware setup to ensure accurate validation.

4. Design & Implementation

In this section, the design and implementation of the SIL and HIL-based validation setup for the Adaptive Cruise Control (ACC) and Instrument Cluster (IC) will be discussed. The focus will be on the architecture, components, and integration of hardware and software systems that form the basis of the validation process which are nothing of simulation and analysis.

1. Test Bench Configuration

The test bench configuration includes the complete setup of hardware and software components used for testing the ACC and IC in a Hardware-in-the-Loop (HIL) environment. The key components of the setup are:

- **Hardware Setup:** The test bench consists of the TCM, ACC, IC and vehicle simulator (IVN), and a controller. These are interconnected via a CAN bus or another suitable communication protocol which are used to facilitate the exchange of data.
- **Software Setup:** The primary software tools which are used for simulation and testing is TS Master, TopWaySGtools. This tool provide an interface for generating test scenarios, monitoring signals, and analyzing data during the test process.

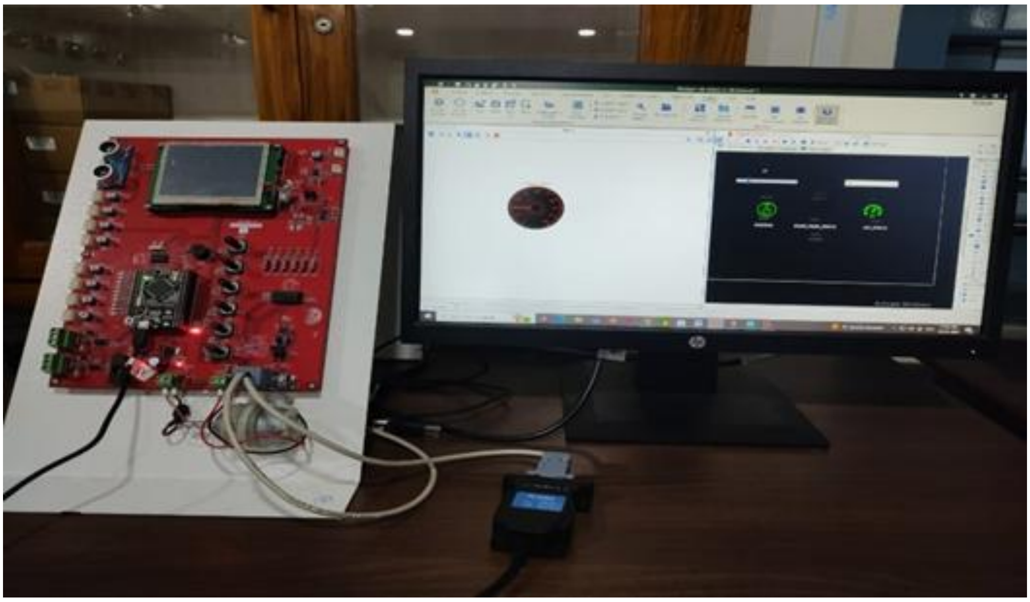

Figure 1: Hardware setup

2. Database Configuration for Validation Process

• **Database for Test Case Management:** A key element of the test process involves the use of a test case database that logs all test scenarios and expected results. The database stores test case details such as:

O Test case ID

O Description of the test scenario

O Expected outcome

O Test execution results

• **Data Logging:** As tests are conducted, TS Master records the test results and stores them in a structured database. This allows for easy retrieval, analysis, and reporting. It also supports efficient tracking of test coverage and performance matrics, such as the accuracy of ACC & IC communication or the response time under different conditions.

• **Test Result Analysis:** After test execution, the database is queried to extract the relevant data points for evaluation and simulation. These can include CAN messages, fault logs, and timing data related to the ACC, TCM and IC functionality.

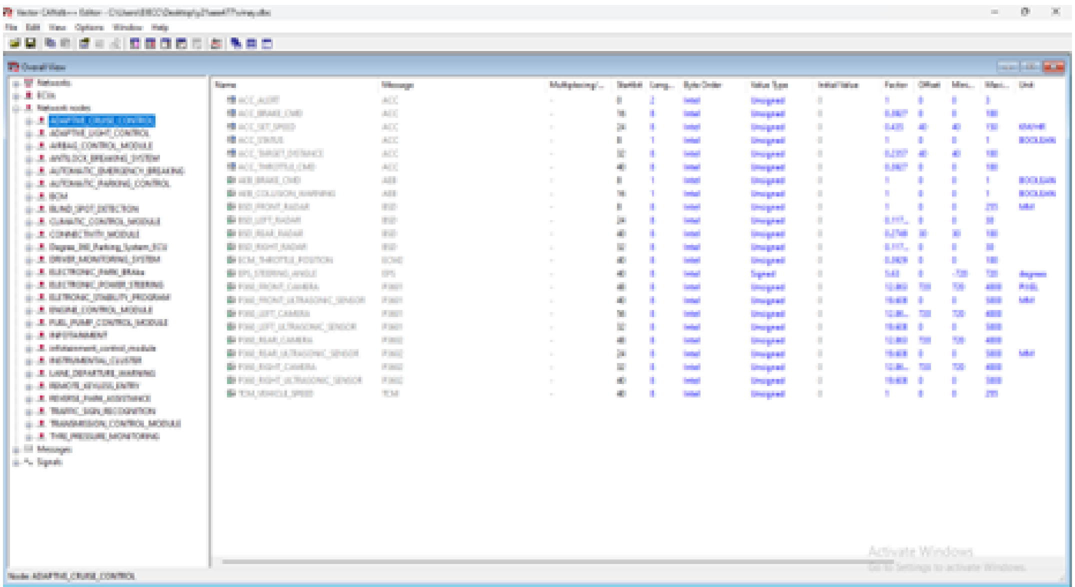

Figure 2: Database of ACC, TCM & IC

3. Integration of TS Master and Topway SG Tools for Monitoring and Simulation

• **TS Master:** This tool plays a central role in monitoring, controlling, and analyzing the interactions between different components in the test bench. TS Master is used for generating CAN signals, simulating different vehicle states, and automating test cases. Through scripting and panel creation, the system is able to simulate complex real-world scenarios and validate the behavior of the ACC, TCM and IC under these conditions.

O Signal Monitoring: TS Master allows for real-time monitoring of CAN signals, enabling users to track the communication between the ACC, TCM, IC, and other vehicle systems.

O Test Automation: The tool facilitates the automation of various test cases through scripting, making it easier to perform repetitive tests and track results.

O Real-time Simulation: TS Master provides a platform to simulate different vehicle states (e.g., engine on/off, door open/close, etc.) and validate the ACC, TCM and IC response under those conditions.

O Data Logging: TS Master logs data during testing, which can later be analyzed for performance, accuracy, and compliance with functional requirements.

Results And Analysis

In this section, we present the outcomes from the Hardware-in-the-Loop (HIL) and Software in loop (SIL) integrated validation process for the adaptive cruise control (ACC) transmission control module (TCM) and Instrument Cluster (IC). expected under various simulated vehicle conditions. Additionally, this section includes an analysis of the test performance, observations, and conclusions drawn from the data which is collected through the simulation and analysis.

The Adaptive Cruise Control (ACC) system simulated using TSMaster and CAN communication successfully maintained safe distances and adjusted speeds in response to dynamic lead vehicle behavior. The system showed smooth transitions, quick response times, and effective control accuracy across various virtual traffic scenarios.

1. Test Results:

The SIL and HIL testing process was carried out using the integrated setup involving TS Master and TopwaySG tools for simulating the vehicle functions and ACC-IC interaction. The tests were designed to cover a wide range of vehicle conditions and edge cases to assess the functionality and response of the ACC, TCM and IC.

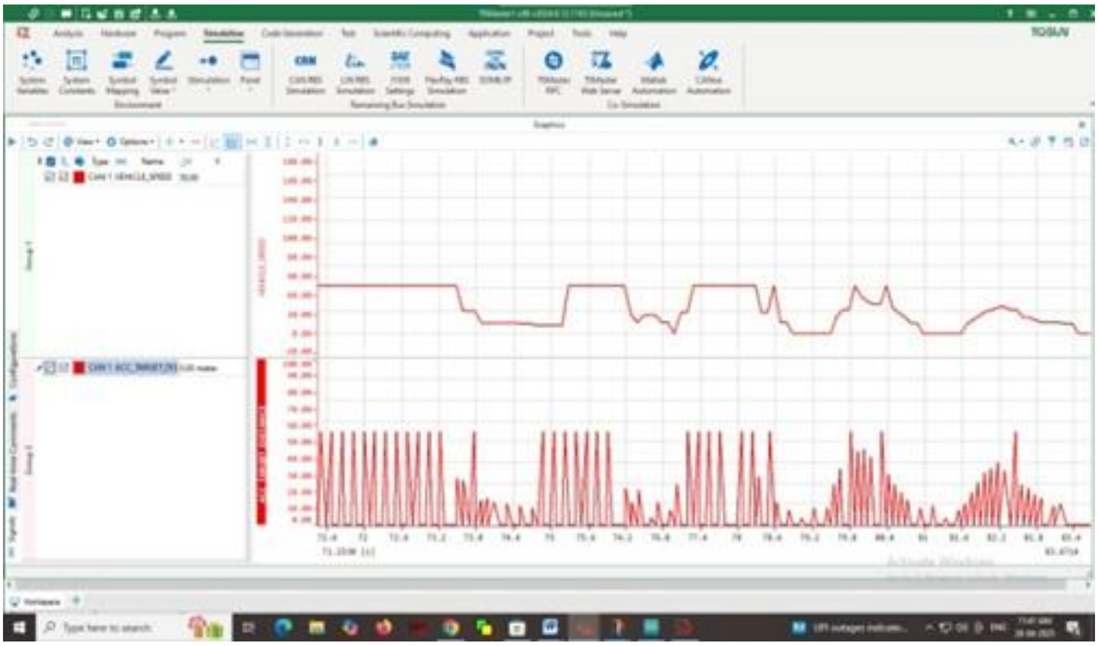

Figure 3: obtained result

Key Areas Tested:

• **Communication Integrity:** The communication between the ACC, TCM and IC over the CAN bus was continuously monitored during the tests to verify that the correct data (speed, set speed, emergency breaking and vehicle distance) was being transmitted and displayed accurately.

• **Real-Time Response:** The response time of the ACC and IC when switching between different states (e.g., from vehicle speed to set speed) was tested to ensure timely updates.
• **Simulation of Vehicle States:** Multiple vehicle states were simulated, such as acc activation, brake pedal, set speed etc., to assess how the TCM&ACC responds and updates the IC accordingly.

Test Case Execution:

• Test cases were executed, and data was logged for each scenario, including CAN signal measurements, error codes, timing data, and status updates.
• Real-time simulation scenarios included vehicle behaviours like ACC activation, emergency braking, set speed and brake pedal state where the TCM was required to communicate the status to the IC.

2. Analysis of Results

The collected data was analyzed to evaluate the performance of both modules under the simulated conditions. The following parameters were considered in the analysis:
• **Accuracy:** The accuracy of the data transmitted between the TCM,ACC and IC was verified by comparing the transmitted values with expected results. All tests confirmed that the IC displayed the correct information based on the input from the TCM.
• **Speed:** The IC correctly reflected changes in vehicle speed.
• **Warning Signals:** Warning signals like emergency braking and ACC malf were accurately triggered and displayed on the IC as per the TCM and ACC inputs.
• **Reliability:** The system showed high reliability during the tests, with no failure to respond or missed messages between the TCM, ACC and IC.

5. Future Scope

In the present work, Adaptive Cruise Control (ACC) has been successfully simulated using TSMaster software and a CAN database for in-vehicle network communication. As a future extension, this system can be integrated with Traffic Sign Recognition (TSR) functionality to create a more intelligent and responsive virtual driving environment. By incorporating TSR, the ACC system can adapt vehicle speed and behavior dynamically based on detected traffic signs such as speed limits, stop signs, or caution zones. This integration will enhance the realism of the virtual simulation, improve system safety responses, and align with the development of advanced driver-assistance systems (ADAS) for autonomous and semi-autonomous vehicles

Integration with Advanced Driver Assistance Systems (ADAS)

As vehicles become more autonomous and feature-rich with ADAS technologies, integrating these systems into the automotive environment will be essential. The future scope includes:
• Cars could share position/speed data with each other and traffic infrastructure (e.g., smart traffic lights).
• AI & Predictive Control: ACC systems will anticipate behavior of other vehicles and adapt accordingly (e.g., detecting cut-ins).
• High-Definition Maps: Integration with navigation for proactive speed control (e.g., slowing before curves or exits).
• Next-Gen Sensor Fusion: Combining RADAR, LIDAR, ultrasonic and vision sensors into a single coherent "perception system."

6. Conclusion

The Adaptive Cruise Control (ACC) system was successfully designed and virtually simulated using TSMaster software with CAN database communication. The system effectively maintained safe distances from leading vehicles by adjusting speed dynamically. Virtual simulation proved to be an efficient method for testing and validating ACC behavior without physical hardware. This project lays the groundwork for future integration with Traffic Sign Recognition (TSR) systems to enhance autonomous driving capabilities.

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