

A Vision-Based Forward Collision Warning System Developed under Virtual Environment

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ABSTRACT

This paper presents a novel approach of developing a vision-based forward collision warning system (FCW) under a virtual and real-time driving environment. The proposed environment mainly includes a 3D high-fidelity virtual driving environment developed with computer graphics technologies, a virtual camera model and a real-time hardware-in-the-loop (HIL) system with a driver simulator. Some preliminary simulation has been conducted to verify that the proposed virtual environment along with the image generated by a virtual camera model is valid with sufficient fidelity, and the real-time HIL development system with driver in the loop is effective in the early design, test and verification of the FCW and other similar ADAS systems.

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INTRODUCTION

Advanced driver assistance systems (ADAS) have gained increasing popularity in recent years, as traffic safety and efficiency have become two of the major challenges faced by automotive industry. Vision-based ADAS systems have received particular attention, partially due to the cost advantage of camera versus radar or lidar. This makes ADAS products more attractive and practical to the market. In addition, the technological advancement in image processing (IP), pattern recognition (PR) and digital signal processing (DSP), to name a few, has also greatly contributed to the feasibility and maturity of the vision-based applications on ADAS. Vision-based forward collision warning (FCW) system is one of the typical applications, designed to prevent incoming dangerous situations by warning drivers.

Conventionally the ADAS systems are developed, tested and validated mainly based on intensive field experiment under various driving scenarios. However, the large variation, uncertainty and complexity of the driving environment with road, traffic, weather and lighting conditions have posed great challenges for testing ADAS to ensure test repeatability and system robustness. More importantly, the field testing can be dangerous if not impossible for some safety critical features.

Some commercial tools were developed with attempt to address the issues through modeling and simulation technologies on vehicles and/or vehicle driving environment [1] [2][3][4]. While they were developed with different emphases on specific applications, the technologies are in general more mature in conventional vehicle dynamics and control areas than in ADAS. This paper proposes a virtual vehicle driving environment with not only vehicle dynamics models, but also real-time virtual driving environment. The aim is to enable the high-fidelity design, test and verification of the ADAS systems. The proposed environment mainly includes models of vehicles, traffic and on-board perception sensors; virtual road, traffic, and weather conditions; and a 3D high-fidelity virtual image world developed based on computer graphics technologies and a real-time hardware-in-the-loop (HIL) system with a driver simulator.

The paper is organized as follows: Section II presents the proposed virtual real-time vehicle driving environment, more specifically for FCW development. The FCW algorithm is developed under this virtual environment which is to be discussed in Section III. Some simulations are conducted with the results shown in Section IV demonstrating the validity of the proposed approach. Section V concludes the paper with a brief summary.

REAL-TIME VIRTUAL DRIVING ENVIRONMENT

The 3D high-fidelity virtual driving environment is developed with the aim to reduce the in-vehicle field testing, thus to reduce the development cost and to shorten the development cycle, and more importantly, to achieve test repeatability and performance robustness with broader coverage on large variation of the driving environment. Under the proposed virtual environment, there are modeled road and pavement with high-fidelity texture, traffic simulator, buildings, tree and bushes, etc. Besides, the real-time HIL system includes a nonlinear real-time vehicle dynamics model, running under a dSPACE HIL-simulator to simulate the host vehicle with a simplified model to simulate the traffic vehicles, a virtual sensor model to simulate in-vehicle environment sensor, such as camera. A driver simulator with 6 degree-of-freedom (DOF) motion platform is also utilized for human drivers to evaluate the performance of the ADAS.

An FCW system is developed under this virtual vehicle driving environment with a virtual world, rendered under a graphics processing unit (GPU); a virtual camera model, developed to capture the image from the well-design computer graph with similar quality as the image captured from the real camera. The camera position and orientation, focus, and the image resolution and size can be adjusted as needed. The captured virtual image is then sent to the image processing unit (IPU) for obstacle detection and distance estimation, lane marker detection and lane estimation, etc. [Figure 1](#) shows the developed real-time virtual driving simulation platform.



Figure 1. A Real-Time Virtual Driving Environment

Hardware Components

The real-time HIL system includes several major hardware subsystems, such as a host PC, a dSPACE DS1006-based HIL simulator, several DS1401-based MicroAutoboxes(MABX), a SEED8168 DSP board, an ARM board, and a full driver simulator:

- The host PC is used for generating a virtual world through computer GPU, and for displaying vehicle motion through animation.

- The dSPACE -based HIL simulator is used to host the nonlinear real-time vehicle dynamics model and simplified traffic vehicle models to simulate the road traffic.
- Several dSPACE MABX hardware devices are used as prototype controllers to run the FCW algorithm (dSPACE1401II) and to acquire driver input signals (dSPACE1401I). They all communicate with the dSPACE HIL-simulator.
- A SEED8168 DSP board is used as an image processing unit for obstacle detection, pattern recognition and estimation, and lane markers detection and estimation.
- An ARM board is used as a user terminal and for HMI processing that generates warning sign and signals on the screen.
- A driver simulator with 6 DOF motion platform is also utilized, with full motion of pitch, yaw and roll and three translational motions, for human drivers to evaluate the performance of the FCW system.

These subsystems are connected and communicated with each other via CAN buses and/or Ethernet cables that emulate the real vehicle electrical architecture for adoption to in-vehicle field test.

[Figure 2](#) illustrates the system architecture with hardware subsystems and components.

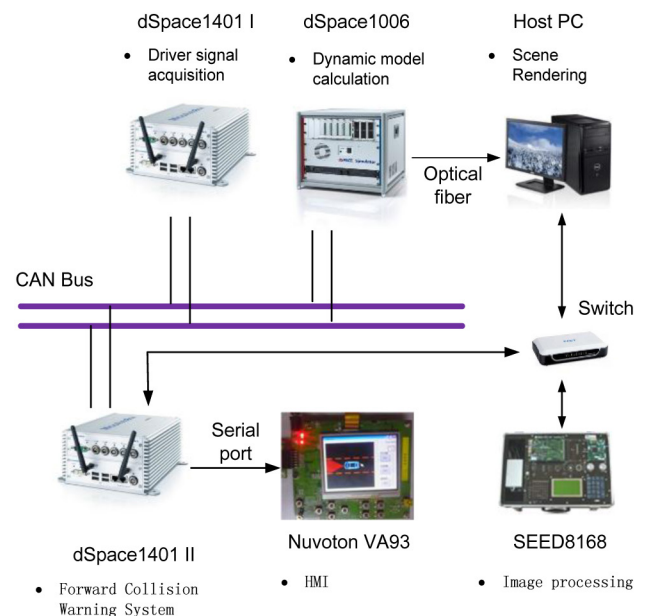


Figure 2. Architecture of Virtual Driving Environment

FORWARD COLLISION WARNING SYSTEM

The forward collision warning system consists of two modules: image processing module and pre-warning module as shown in [Figure 3](#). The image processing module is running on a SEED8168 DSP board, and provides environment perception, such as detection on target and lane markers, etc. On the other hand, the pre-warning module consists of four main sub-