2007-01-0515

Design and Implementation of an Integrated Development Environment Consisting of Engine Rapid Control Prototyping and Real Time Vehicle Simulation

Shugang Jiang, Dharshan Medonza, Satoshi Furukawa and Michael Smith
A&D Technology Inc.

ABSTRACT

To meet the ever increasing requirements for engines and vehicles in the areas of performance, fuel economy and emission, and reduce product development time, we see the need for an integrated development environment which combines engine rapid control prototyping (RCP) capability with real-time vehicle simulation capability using an engine dynamometer in the test cell. Design and implementation of such a system with the ADX universal high-speed system controllers are described. An application example of simulating an FTP-75 cycle in the test cell while the engine is under ADX control is presented. This system moves a lot of work from the whole vehicle environment to the engine test cell environment, and is a powerful tool for quick development and testing of control algorithms as well as calibration.

INTRODUCTION

In recent years we have seen a trend in the automotive industry where more and more electronic systems are being installed on vehicles. Moreover, the functions of the electronic systems are becoming more and more complex. This has been driven by the ever increasing requirements of safety, fuel economy and environmental protection, etc. Meanwhile, OEMs are continually seeking to shorten the product development cycle in order to survive the fierce market competition. Under such a situation the market sees a great need for methods for rapid development, testing and calibration of vehicle subsystems. This has led to the rapid adoption of model-based development of control systems. Model-based development provides solutions to quickly prototype complex control strategies and carries out testing and verification in an efficient way. With the use of rapid prototyping methods, new algorithms can be specified in a high-level graphical language and directly compiled into executables to be implemented and tested on real-time hardware. Because of the seamless transition from simulation to implementation and testing, system behavior can be assessed and tested in every development phase. Due to these advantages, model-based development has become an essential part of the development processes for modern automotive control strategies, especially in engine control system development.

It is also ideal during engine control system development that as much work as possible in algorithm design and ECU calibration be carried out in the engine test cell, before we have to perform at the vehicle level. In fact it is very often the case that whole vehicle integration is not available when engine control development is performed. Moreover, development work in the engine test cell provides better monitoring of engine behavior as well as good repeatability of the test runs. Because of the above reasons, real-time vehicle simulation using an engine dynamometer in the test cell is greatly desired.

Thus we see the need for an integrated development environment which combines the engine RCP capability and real-time vehicle simulation capability in the test cell. Such an environment provides the developers with a comprehensive method to quickly and efficiently carry out development, evaluation and verification of engine control strategies and to quickly calibrate and optimize the performance of engine systems. Seamlessly integrating the engine prototyping controller and real-time vehicle simulation bench moves a lot of vehicle-based work into the test cell. It ensures a reliable and consistent process, and is a very desirable development environment for engineers.

This paper presents an effort to set up such an integrated development environment. We used two ADX universal high-speed system controllers in realizing this system --- an RCP Controller, which carries out full pass engine RCP, and a Simulation Controller, which carries out real-time vehicle simulation and test cell control. The RCP Controller provides the hardware and software environment for engine control functions such as spark timing and fuel injection. The Simulation Controller is designed as a model-based dynamometer and throttle controller along with vehicle and driver models to realize real-time simulation of an actual vehicle.

The paper is organized into four parts. First, the features of the ADX high-speed system controller are described. Its hardware and software configurations are introduced. The next section explains the overall design of the integrated development system, followed by a detailed description of the implementation of the full pass engine RCP system, and the vehicle simulation and test cell control system. The third section provides an example of using the integrated development system to simulate an FTP-75 test in the engine test cell while implementing a fuel control algorithm. Finally a conclusion section summarizes the benefit of this integrated development system and gives the direction of future work.

ADX UNIVERSAL HIGH SPEED SYSTEM CONTROLLER

The ADX is a high-speed measurement and control system. Figure 1 shows the hardware framework of the controller. It has a dual CPU architecture, using a PentiumM processor for high-speed simulation and control, and a Renesas SH4 processor for running the human-machine and host communication interface. A bus controller on the active back plane handles the data transfer between the I/O interface boards and the CPUs. This design lets the ADX free up the PentiumM CPU and enables execution of highly efficient digital signal processing operations. The model cycle of the system can be as high as 20 kHz.

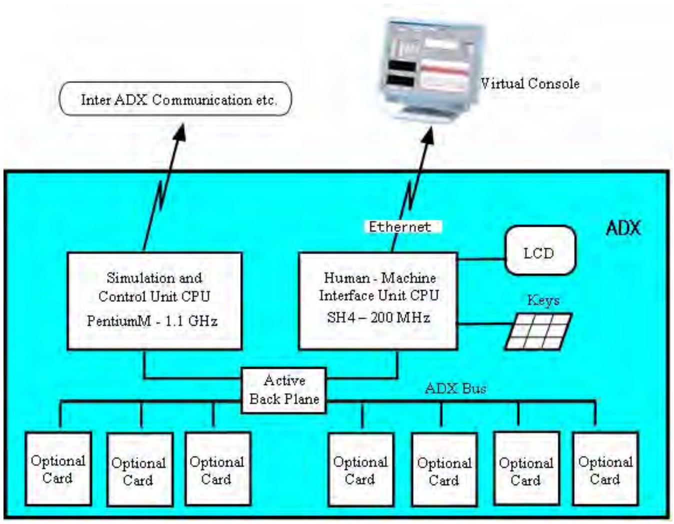

Fig. 1 Hardware Architecture of ADX

The controller has a modular design, and seven slots are available for any combination of dedicated I/O boards. Various user selectable general-purpose (A/D, D/A, DI/O, PWM, thermocouple etc.) and special function interface boards (engine timing detection, three-phase PWM motor control, networking, ECU bypass etc.), as well as necessary Simulink S-functions, are provided. The controller can be configured for a wide variety of applications by combining multiple I/O boards, and it provides very powerful and flexible solutions for control system design, prototyping, simulation and testing. The ADX has a color touch-screen display and 14 function keys which can be customized. The controller can operate as a stand-alone unit, as well as connected to a host PC through Ethernet. It is portable, and suitable for both lab and in-vehicle use.

Figure 2 shows the software architecture of the ADX and the specific role of each software component. MathWorks products --- MATLAB / Simulink / Stateflow --- are used to develop control logic in the form of model block diagrams. Real-time interface blocksets for various functionalities are provided, and the S-functions for system hardware and interface boards can be integrated in the block diagram. Real-Time Workshop converts the block diagram into C code. Then they are compiled, linked, and downloaded automatically to the target platform for real-time execution under the RT-Linux operating system. It uses Virtual Console for a graphical user interface. Virtual Console enables the arrangement of the screen elements (e.g. oscilloscope) by simply selecting control components from the library on the host PC, dragging them onto the screen, and associating them with the variables and parameters of the Simulink model. Virtual Console provides engineers with an interface for real-time parameter setting and signal monitoring.

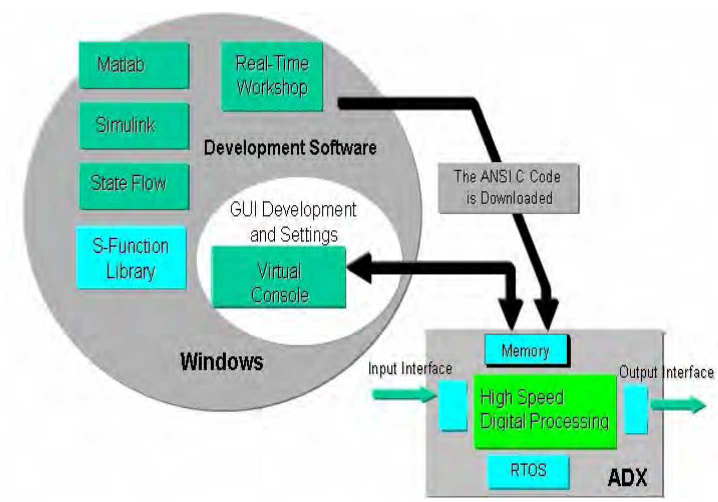

Fig. 2 Specific Roles of ADX Software Components

DESIGN AND IMPLEMENTATION OF THE INTEGRATED DEVELOPMENT SYSTEM

Figure 3 gives an overview of the integrated development environment. The minimum necessary functions for gasoline engine operation are implemented with the RCP Controller. These basic functions provide the framework for additional or more advanced control strategies, which can be added by integrating with MATLAB/Simulink models. The Simulation Controller realizes real-time simulation of vehicle behavior in the engine test cell environment. It runs mathematical models of vehicle subsystems and the driver, and controls the dynamometer and engine throttle. The dynamometer needs to be controlled in such a way that it loads the engine as in a real vehicle. The throttle needs to be controlled in such a way that the desired vehicle speed trace required by the driving cycle is maintained.

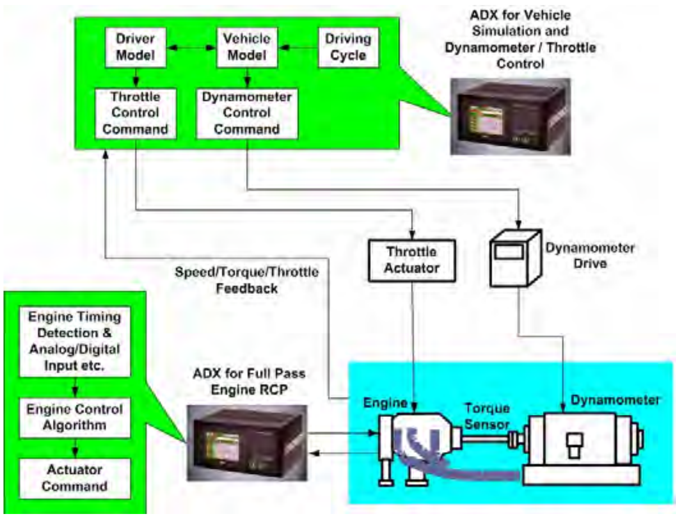

Fig. 3 Overview of the Integrated Development System

Based on application needs, the two controllers can serve as slaves of a higher level central control unit, which is not shown in the figure and will not be covered by this paper. Below we give a brief description of the function implementation of the RCP Controller and the Simulation Controller.

Implementation of Full Pass Engine RCP

Figure 4 shows part of the Simulink Model of the full pass engine controller. An engine timing detection card is used for processing the crankshaft and camshaft input signals and sending out control signals for spark ignition and fuel injection. An analog input card is used for measuring the throttle position and the manifold absolute pressure, which are used for determining engine load. It is also used for the input of the air-fuel ratio signal, thus realizing not only open loop fuel control, but also closed loop fuel control based on the air-fuel ratio feedback. Based on the engine RPM, load information and control parameter settings or adjustments through Virtual Console (spark advance, ignition dwell angle, open/closed loop fuel control mode, fuel injection duration adjustment etc.), the RCP controller implements real-time control of the engine operation. More optional cards, such as D/A, thermocouple, encoder, PWM, digital I/O, serial communication etc., are available to implement various additional control features of the engine.

Real-time crank angle detection and cylinder identification are critical for engine control. The engine timing mechanism is specific to customers and platforms. There are various types of crankshaft and camshaft signals that are currently used by OEMs and suppliers. The engine timing detection card of the ADX controller can handle different types of input signals, e.g., an encoder signal, a missing tooth signal, a chasing tooth signal, a cylinder identification signal etc. An FPGA is used for signal processing and the output of control signals. The card has 16 output channels, which can be

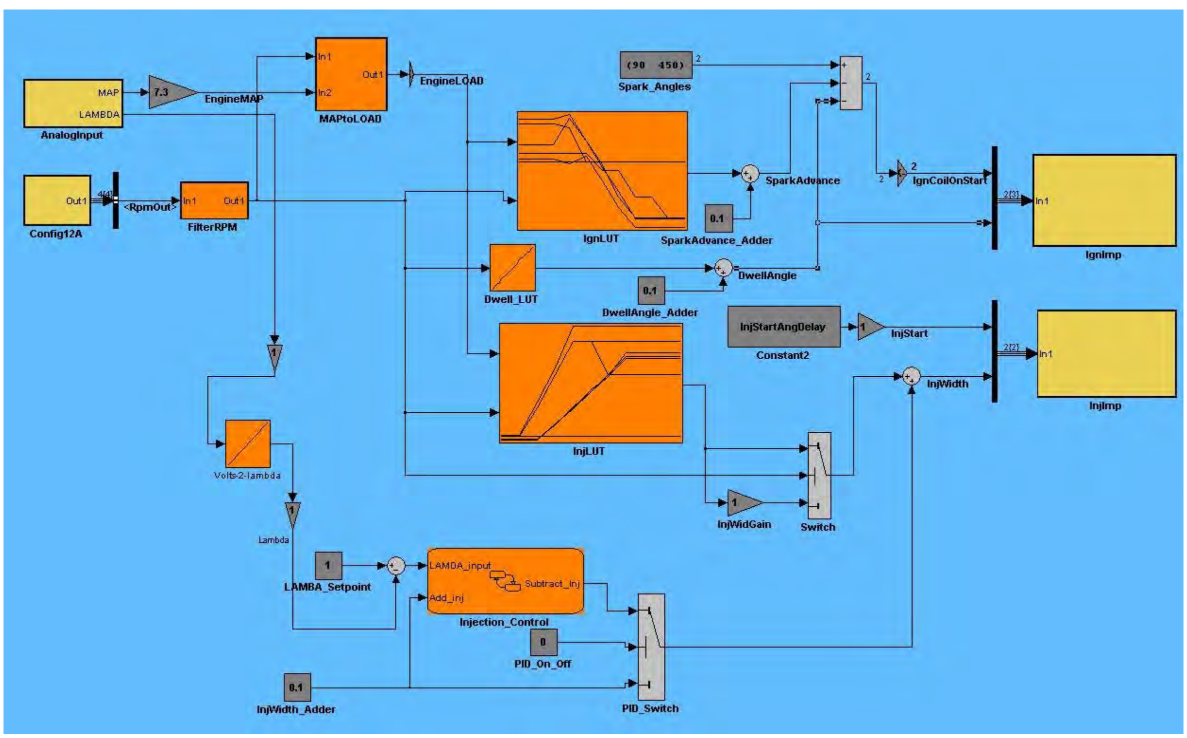

Fig. 4 Part of the Full Pass Engine RCP Model

used for ignition and fuel injection control. The timing resolution can be 1 µsec. The card can be configured and parameter settings can easily be made via the S-functions. For each output channel of the card, in each working cycle (2 crankshaft revolutions) of the engine, it can output as many as 8 pulses for ignition, or as many as 20 pulses for fuel injection. Figure 5 shows a graphical user interface screen that is used to adjust spark advance, ignition dwell angle and fuel injection duration, etc., in real time, as well as monitor related variables for engine behavior.

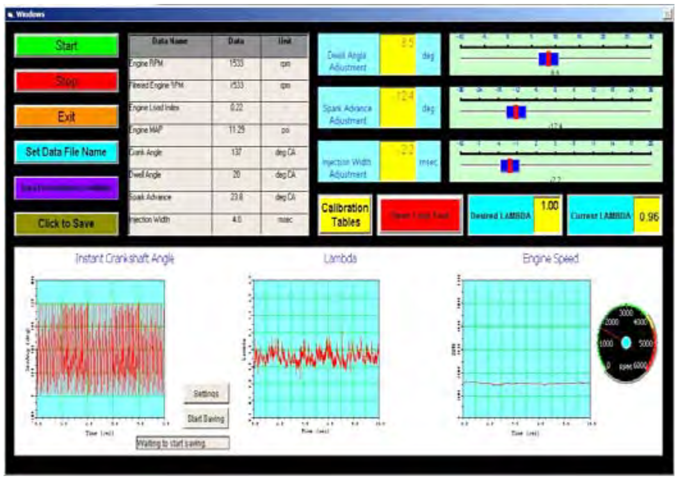

Fig. 5 GUI for Parameter Setting and Variable Monitoring

Implementation of Vehicle Simulation and Dynamometer/Throttle Control

Figure 6 shows part of the Simulink model of the Simulation Controller, which realizes driving cycle settings, vehicle configuration settings, and all necessary calculations of the vehicle model for obtaining the dynamometer and throttle control set point. ADX sends out control commands at a maximum rate of 1000Hz to the dynamometer drive and the throttle actuator. It also has control over the resetting, stopping, and emergency safety mechanism of the drive. The Simulation Controller makes the dynamometer emulate a vehicle to the connected engine.

APPLICATION EXAMPLE

Using this development environment, a fuel control strategy together with other necessary control functions running on the RCP Controller, and a Simulink model for an FTP-75 driving cycle running on the Simulation Controller were carried out. Unlike what we show in Figure 3, a driver model is not used in this example. Instead an operator manually adjusts the throttle input and follows the FTP-75 trace by monitoring the feedback from the system. Figure 7 is an excerpt that shows part of the result of the FTP-75 trace and the speed trace generated by the dynamometer.

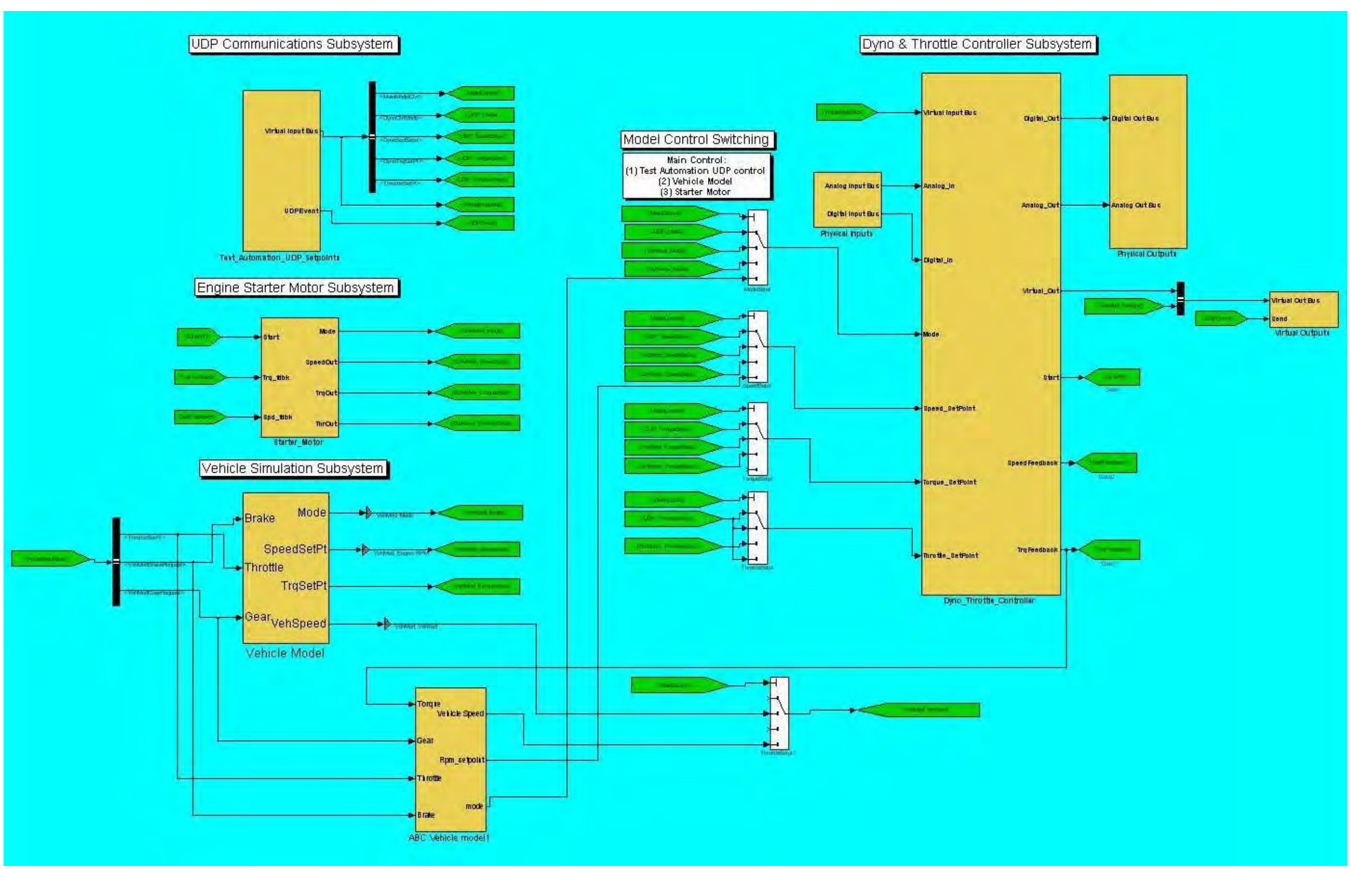

Fig. 6 Part of the Simulink Model of the Simulation Controller

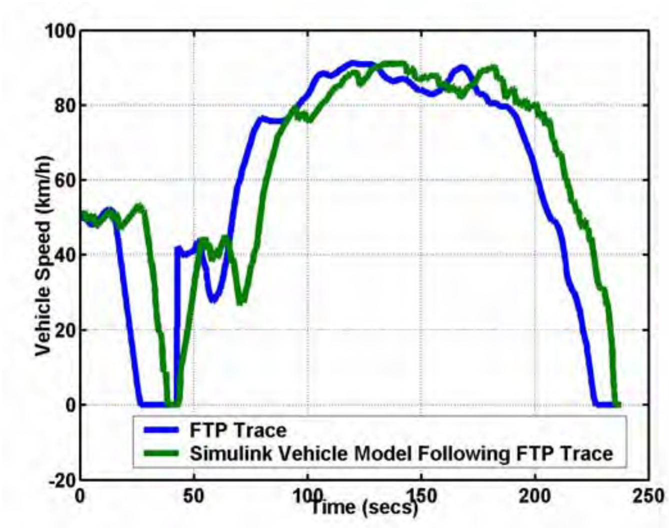

Fig. 7 Excerpt of FTP-75 Trace and Speed Trace Generated by Dynamometer

We can modify the control parameters and monitor engine behavior through the Virtual Console GUI. We also use a high-speed data acquisition system to show how the ignition and fuel injection pulses change in real time during the driving cycle. Figure 8 shows a snapshot of the ignition and fuel injection pulses from the RCP Controller (cam signal and a cylinder pressure signal are also shown in this figure). At the moment, an emissions bench has not yet been installed in the development environment. We will show more about the effectiveness of the whole system in control feature design and performance optimization in later papers.

CONCLUSION

Integrating engine rapid control prototyping with real-time vehicle simulation provides engineers a desirable development environment with comprehensive capability in engine control development. With its high performance design, abundant functional cards and very friendly GUI, the ADX universal high-speed system controllers can be successfully applied to realize such a system. This development environment can effectively move much development work from the vehicle environment to the engine test cell environment, thus greatly reducing the time for control algorithm development and control parameter optimization. Key elements and functions of this system have been set up and some basic applications have been carried out. Results indicate the feasibility and benefit of such a development environment. Further work includes integrating the emission bench into the system and also refining the vehicle model, driver model etc. These will greatly enhance the system capability in transient mode development and enhance the value of the system.

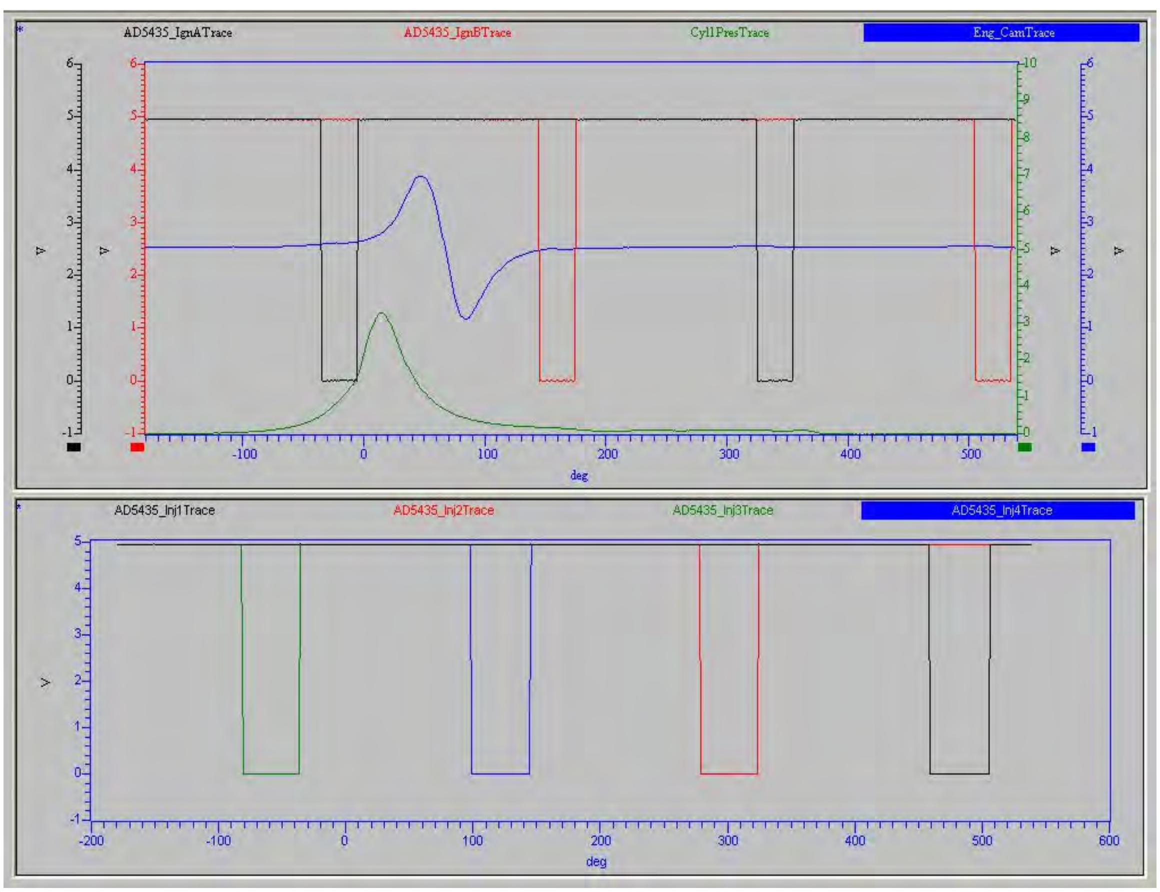

Fig. 8 Ignition and Fuel Injection Pulses

REFERENCES

1. Jooyoung Ma, Jeamyoung Youn and Minsuk Shin, et. al., "A Design Approach using Seamless Development Environments, SILs/RCP, for Real-Time Control Systems", SAE 2006-01-0310.
2. Andrew Beaumont, Joe Lemieux and Paul Battiston, et. al., "Design of a Rapid Prototyping Engine Management System for Development of Combustion Feedback Control Technology", SAE 2006-01-0611.
3. Tom Erkkinen and Koos Zwaanenburg, "A Seamless Implementation of Model-Based Design Applied to a New Fuel Control Feature for an Existing Engine ECU", SAE 2006-01-0612.
4. Seungbum Park, Hakmo Yoo and Youngbug Park, et. al., "Model-based Development of Engine Control System from Concept to Vehicle", SAE 2006-01-0856.
5. Joe Steiber, "Development of an Engine Test Cell for Rapid Evaluation of Advanced Powertrain Technologies using Model-Controlled Dynamometers", SAE 2006-01-1409.
6. Jeffrey D. Naber, Eric K. Bradley and John E. Szpytman, "Target Based Rapid Prototyping Control System for Engine Research", SAE 2006-01-0860.
7. Joe Steiber, Bapraju Surampudi, Ben Treichel, et.al., "Vehicle HIL, the Near Term Solution for Optimizing Engine and Transmission Development", SAE 2005-01-1050.
8. O. Philipp, M. Buhl, S. Diehl; et.al., "Engine ECU Function Development Using Software-in-the-Loop Methodology", SAE 2005-01-0049.
9. Mark Hsu, Maher El-Jaroudi and Eric Bender, "Accelerated Life Cycle Development for Electronic Throttle Control Software using Model-based/Auto-Code Technology", SAE 2004-01-0276.
10. Michael Beine and Rainer Otterbach, "Development of Safety-Critical Software Using Automatic Code generation", SAE 2004-01-0708.
11. Kurt B. Plischke, "Bringing MATLAB Into the Test Cell", SAE 2003-01-1025.
12. Paul Cook, Peter James and Mark Willows, "Rapid Prototyping of Generic Hybrid Concept Vehicles", SAE 2002-01-0755.
13. Joseph J. Lemieux, "Foundation for Rapid Embedded Development", SAE 2001-01-0022.

CONTACT

Dr. Shugang Jiang
Technical Specialist
A&D Technology Inc.
4622 Runway Blvd., Ann Arbor, MI 48108 USA
email: sjiang@aanddtech.com