

Control System Development for the Dual Drive Hybrid System

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ABSTRACT

Automotive manufacturers continue to move further toward powertrain electrification. There are already many hybrid electric vehicles on the market that are based on a variety of system architectures. Ford Motor Company has investigated a new Dual Drive configuration that promises to overcome some of the attribute deficiencies associated with current architectures. The primary objective of this development project was to demonstrate the fuel economy potential of this system in a vehicle. To accomplish this objective, the team used an internally developed, formal Controls Development Process (CDP) for the control system design and validation. This paper describes the development of the vehicle control system in the context of this process.

INTRODUCTION

Today's economic conditions for automotive consumers and global environmental concerns continue to drive demand for more fuel efficient vehicle powertrains. Over the past two years, prices for oil and gasoline have reached record levels in much of the industrialized world [1]. This has caused consumers to put a renewed emphasis on fuel economy as a critical factor in their purchase decisions for automobiles. At the same time, global concerns over climate change and greenhouse gases have caused both consumers and governments alike to demand higher fuel efficiency in new automobiles. In Europe, carbon dioxide targets that have been voluntary for automobile manufacturers are now under consideration as legal limits. Similar legislation in the United States is under consideration.

Automotive OEMs have responded to this changing market demand by developing and introducing a host of new efficiency improvements in their vehicles and powertrains. These range from engine improvements such as direct injection and variable displacement to transmission advances such as six and eight speed designs and dual clutch technology [2]. Although these technologies provide important incremental fuel economy improvements, they do not provide the more sizable gains that are achievable through powertrain hybridization. Moreover, in order to evolve to a society where vehicles are not a significant contributor to atmospheric greenhouse gases, substantial vehicle electrification will likely be required. Hybrid powertrains are a major step in ultimately moving toward plug-in hybrid, battery electric or fuel cell vehicles. For these reasons, nearly every major automaker has begun introducing hybrid offerings in their powertrain lineups [3].

There are numerous ways to couple an electric motor (or motors) to an engine and a driveline, resulting in a wide variety of possible hybrid powertrain configurations. For any individual configuration, component sizing, control algorithm development, and calibration can be tuned to optimize vehicle behavior for a particular attribute (e.g. fuel economy, drivability, etc.). However, certain configurations are limited in their ability to meet individual attribute requirements due to the system's underlying kinematic arrangement and complexity. For instance, the most popular hybrid configuration on the market today, the powersplit system (variations of which are used in several Ford and Toyota vehicles), is limited in its towing capability due to its specific arrangement of motors, gears, and engine.

The control system development described in this paper is for a "Dual Drive" hybrid configuration. This system,

various subsystem controls in order to achieve the overall coordination. Figure 2 shows the high-level functional relationship between the vehicle controls and the subsystem controls.

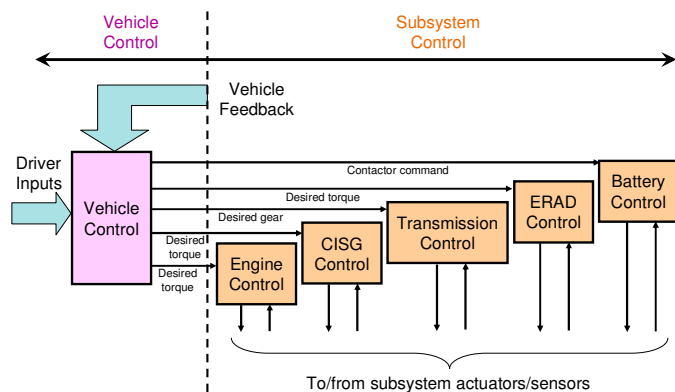


Figure 2: Vehicle vs. Subsystem Control

OBJECTIVE OF CONTROL SYSTEM DEVELOPMENT

The primary objective of the Dual Drive hybrid system development project was to demonstrate the potential fuel economy benefit of this system in a vehicle while achieving acceptable levels of other attributes such as drivability and performance. The success of this objective was measured by the ability of the vehicle to follow the fuel economy speed trace with acceptably low variability for repeated runs, and by the ability to meet a target of 20% reduction in fuel consumption (FC). This FC reduction target was set through simulation studies. To accomplish this objective, the team used an internally developed Controls Development Process (CDP) for control system design and validation. Key elements of the CDP include: Requirements Definition, Architecture Development, Functional Decomposition and Interface Definition, Function Design, Implementation, and Verification / Validation. The development of the Dual Drive control system will be described in the context of these CDP elements.

CONTROL SYSTEM DEVELOPMENT

The CDP was created by applying the principles of systems engineering to control system development. The CDP used in this project does not stipulate a new way to develop controls; rather it is a collection of best practices used internally at Ford and within the industry applied in a logical, coherent, and traceable manner. Figure 3 shows the flow of steps in the CDP.

REQUIREMENTS DEFINITION – The CDP discussed in the paper is a requirements centered process. Each design, robustness, and validation activity is tightly coupled to one or more requirements. While requirements can be seen as a part of each stage of the CDP, this early phase focuses on gathering and defining the overall set of control system requirements.

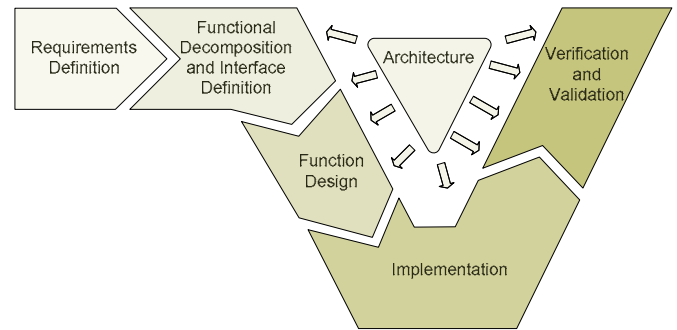


Figure 3: Controls Development Process

This task was broken down into two key steps. First, existing requirements and design constraints were gathered. Government regulations such as the Federal Motor Vehicle Safety Standards (FMVSS), and other existing corporate requirements are examples of two types that need to be considered. This set of incoming requirements will have an impact on how the control system is defined. Second, a set of customer level use cases were captured. An example of a use case is, "Operator drives away from a stop with a 25% accelerator pedal tip-in." This example use case could define when the engine is expected to start and how the subsystems are expected to behave during this driving maneuver. The combined set of incoming requirements and use cases became the defining set of top level vehicle controls requirements.

ARCHITECTURE DEVELOPMENT – Architecture means many different things to many people [4]. The role of architecture in the CDP is a fluid one. It is not a single phase in the development process; instead it is integrated into each phase. Depending on the task at hand it may be appropriate to provide a guiding principle, (e.g. all safety critical functions shall fail safe) and in other cases the architect will provide a functional decomposition with detailed interface definitions. Ultimately, the goal of architecture is to guide and constrain the design. One key task of the architect is to decide what aspects need to be constrained. By carefully choosing which parts of the process to constrain, the system can be significantly shaped by a relatively small set of design constraints.

There were three critical architectural decisions made in this project. First, a functional view of the control system was developed early in the process. The functional decomposition was kept to a high level and only a few interfaces were loosely defined. Second, the software implementation was decomposed into a set of features and functions. Third, the simulation environment was structured to follow the principles of the Vehicle Model Architecture (VMA) [5]. The plant model architecture did not directly impact the control system, but it did provide the infrastructure to facilitate functional development and testing in a Model in the Loop (MIL) and Hardware in the Loop (HIL) setting. Each of these three architectural decisions will be discussed in detail later in the paper.