TASKING

MITIGATING POWERTRAIN CONTROL MODULE DESIGN CHALLENGES

INTRODUCTION

Every modern car, whether it's the humble family minivan or a Formula One racing demon, features a powertrain control module (PCM) — a technological marriage of the engine control module (ECM) and transmission control module (TCM). Comprising tightly integrated high-performance hardware and advanced embedded software, the PCM is ultimately responsible for the vehicle's performance on the road. If you're a software architect designing PCMs, you are faced with one of the most challenging jobs in the automotive industry: electronically control and integrate hundreds of moving parts, with thousands of possible error codes.

As PCMs become more complex to keep pace with increasing fuel efficiency, environmental, and safety regulations, PCM design becomes more challenging. Developers need more sophisticated compilers and performance optimization tools to meet those challenges.

PCM EVOLUTION[1]

The powertrain is the heart of vehicle movement: the engine (cylinder block and head, connecting rods and crankshafts, pistons, turbochargers, valve trains, and more), the exhaust system, the transmission, the drive shaft, suspension, and the wheels. The PCM typically controls more than a hundred factors, including idle speed, variable cam timing, shift scheduling, ignition, catalyst temperature, electronic throttle, fuel pressure, misfire detection, cruise control, and knock detection, just to name a few. Each of these aspects can be associated with several error codes, which indicate that some subsystem of the car is experiencing a problem. When one of these errors occurs, it usually activates the "check engine" light on the dashboard.

Some electronic controls for the drivetrain were introduced in the 1970s. The 1980s saw widespread use of hybrid digital/analog engine control systems, which used analog sensors combined with an electronic ROM chip that stored data that was used to activate various mechanical engine controls.(1) With the emergence of global environmental regulations in the 1990s, the automotive industry responded with electronic emission control devices like catalytic converters, more advanced electronic engine controls, and fuel-injection systems. As the ignition systems became more complex, so did the Engine Control Units (ECUs), so they could better control the air/fuel mixture (Figure 1).

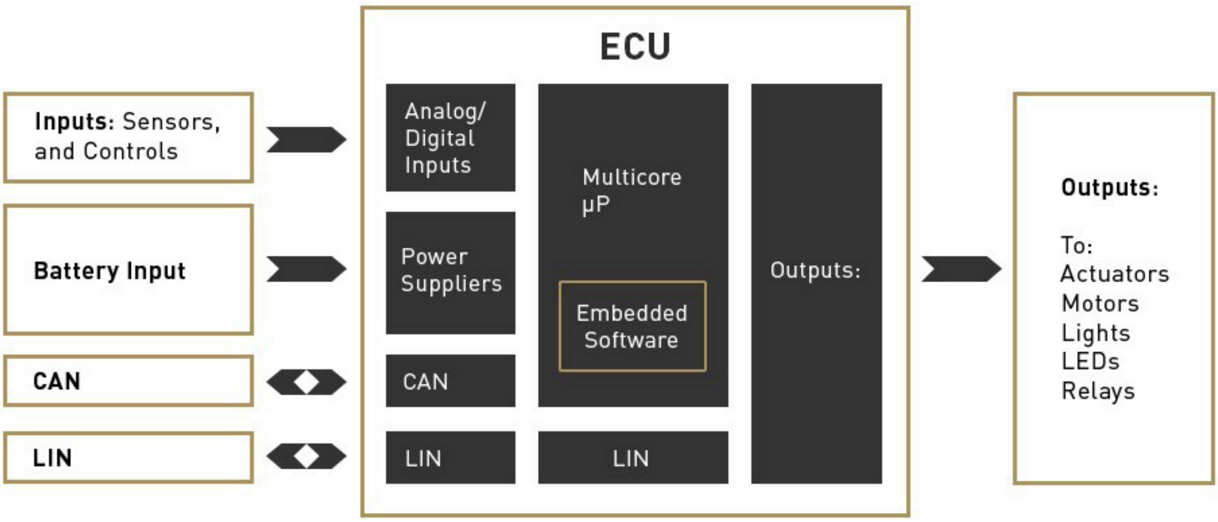

Figure 1. The powertrain control module (PCM) electronically controls and integrates hundreds of parts associated with vehicular movement.

The global automotive ECU market, which includes PCMs, is expected to reach nearly USD 46 billion by 2020.(2) This growth is fueled by technological advances that enable cost-effective new features, along with several market trends:

- Fuel efficiency and environmental regulations. PCMs must meet demanding emission requirements, such as the 2025 U.S. corporate average fuel economy (CAFE) of 54.5 mpg, compared to a CAFE of 27.8 mpg today.(3) As evidenced by the 2015 Volkswagen emissions scandal, also called “dieselgate,”(4), the functionality of PCMs is under close scrutiny by regulatory agencies; as a result, PCM design has become more important than ever.
- Stringent safety requirements. Safety has always been paramount in the automotive industry, but with the rise of advanced driver assistance systems (ADAS) and autonomous vehicles, safety becomes even more important.
- Hybrid electric vehicles. PCMs for hybrid electric vehicles must control not only the traditional engine, but also the electric engine, battery charging, and gearbox management.

To handle new PCM features, PCM memory architectures are becoming increasingly complex. To best utilize these memory architectures, PCM developers need cutting-edge software development tools, such as compilers and linkers, that support memory configuration and performance optimization.

PCM DESIGN CHALLENGES

PCM designers face a number of common challenges (Figure 2):

- Failure analysis. Sensors fail much more frequently than PCM components—but how does the PCM’s embedded software differentiate between a bad ECM and a bad sensor? Embedded software modules must be able to differentiate and initiate the appropriate corrective action. A 2013 study showed that early diagnosis of engine damage is extremely important and that faulty electronic control systems, bad ignition timing, and engine management malfunction may result in the complete destruction of the engine. (5)
- Safety requirements. No one wants their car to suddenly shift into reverse at 55 mph. Get the fuel mix or timing wrong and an errant spark can cause catastrophe. PCMs must be “fail-safe,” which means they must adhere to the ASIL D, the highest Automotive Safety Integrity Level. If something goes wrong, the error must be detected and the system brought into a safe state within a specific time period. Choosing reliable, certified hardware with low fault levels and microprocessors that offer lockstep execution can increase safety; powerful debugging and safety check features in software development tools can also be useful.
- Power consumption. Like most areas of electronics, the more compute power you have, the higher energy use climbs. But power-hogging PCMs are not cost-efficient and they can generate excessive heat that can affect performance. Tightly written code running on energy-efficient hardware is the best combination to beat the energy blues.

POWERTRAIN CONTROL MODULES IN ACTION (10)

Formula One Racing cars put Powertrain Control Modules (PCMs) through their paces. For example, the nature of the circuit can require the engine mappings to change drastically. On slower and twistier tracks (such as the Monaco Grand Prix), the engine control system must help the driver have more control over the throttle by making the first half of the pedal movement very sensitive. On high-speed circuits such as the Italian Grand Prix, the driver needs to use the throttle more aggressively, so the accelerator is set so that only a small movement will result in full engine acceleration.

There are between 100 and 150 sensors on a Formula One race car. Readings are taken every 20 milliseconds, generating 100 KB to 0.5 MB of data per second. A single Grand Prix weekend can create 100 GB of data (enough to fill about 250 DVDs).

- Harsh operating environment. Other than the Antarctic, possibly the worst place to put sophisticated electronics is under the hood of a car. Excessive vibration and wide temperature variations (-40° to 125° C), combined with intense radio interference from the ignition system, require the PCM to be extremely robust and ruggedized, while still being contained at about 60 cubic inches (approximately 6 x 5 x 2).
- Superb performance. Today's PCM applications require fast, multi-core, 32-bit microprocessors that are reliable and energy-efficient, and that offer improved memory performance. Choosing a state-of-the-art compiler can help achieve timing and memory access goals. In addition, the real "brains" of the PCM—the embedded software—must be tightly written and have access to the low-level performance features of the microprocessor. In particular, hybrid electric vehicles and standard regulations have significantly increased the number of application-specific algorithms and calibration datasets to handle differing fuel types and geographic requirements. PCM memory requirements have increased almost eight-fold in the past decade, and are likely to continue increasing—total hybrid and electric vehicle production is forecast to reach USD 11.6 million by 2020, a CAAGR of over 28 percent.(6)
- Secure connectivity. Modern PCMs are beginning to support full-functionality over-the-air (OTA) updates. OTA software component updates help avoid costly recalls, and keep vehicles' systems current throughout their life—more than 51 million vehicles were recalled in 2015 in almost 900 separate recalls.(7) Of course, security is of paramount concern when updating crucial automotive components. This is not the stuff of the future—recently, a next-generation connected car solution was demonstrated at TU-Automotive Detroit 2015, one of the largest and longest-running connected car and auto-mobility conferences in the world.(8) Also in 2015, Navistar Inc. became the first heavy commercial vehicle manufacturer to endorse an OTA control module in its International Trucks fleet, using a Wi-Fi-enabled PCM. The OTA ECM market is poised to exhibit a promising double-digit CAGR in the next ten years.(9) PCM developers can benefit from choosing microprocessors and software development tools that support an integrated hardware security module (HSM) as well as encryption and tamper detection.

Figure 2. Many design challenges face software developers for powertrain control modules (PCMs).

THE RIGHT HARDWARE AND TOOLS CAN MAKE ALL THE DIFFERENCE

Using the right microprocessor can minimize PCM design challenges by offering specific capabilities that address areas of concern such as safety, security, and performance. You should look for a multi-core microprocessor that is heavily used in the automotive industry and that offers lock-step execution, an integrated HSM and generic timing module (GTM), and hardware Fast Fourier Transform (FFT). These features make your design easier by doing the heavy lifting in the hardware itself, instead of requiring the software to do all the work.

Beyond the microprocessor, the compiler and associated software development tools can substantially reduce embedded software time to market by making development and testing easier. Here are some compiler features to look for:

- Hardware optimization. Some compilers are optimized for a certain microprocessor, maximizing the usability of features such as safety, security and timing modules, and multiple cores. Such a compiler generates efficient and compact code—that is, code with the smallest footprint and fastest execution possible. A compiler suite that allows developers to address all relevant hardware features (HSM, GTM, and various cores) strongly improves time to market because virtually all code can be written in high-level C rather than in Assembly, and debugging is simplified as debug information for all hardware components is derived from a single tool suite, guaranteeing compatibility.
- Pin mapping and other low-level interfaces. Advanced automotive microprocessors can have between 100 and 600 pins; keeping track of pin assignments manually can be tedious, time-consuming, and error-prone, especially in advanced PCM applications involving multiple on-chip peripheral modules. Choose a software development suite that includes pin-mapping capabilities as well as interfaces for configuring low-level drivers, header files, and the real-time OS (RTOS).
- Industry compliance and compatibility. While Assembly Language is adequate, it's usually much easier to write optimal-performing PCM algorithms in C or C++. Chose a compiler that supports your language of choice and that has been documented as reliable, ISO-compliant, competitive, complete, compatible, and easy to use. The chosen compiler should comply with authoritative validation suites, such as Perennial ® and Plum Hall[sak2] [JG3] ®, and have been tested in large, real-world PCM applications and against industry benchmark standards such as Nullstone and EEMBC[AH4] .[5]
- Freedom from interference. With safety at the forefront, PCM software developers will appreciate an embedded software development suite that offers freedom from interference between software elements with incompatible ASIL classifications in an application. State-of-the-art interference avoidance tools go beyond traditional static analysis tools that check for dangerous code constructs against the specification, interacting closely with the hardware to bridge the gap between ISO 26262 requirements and traditional software tests.
- Support for ASPICE CL2. Automotive SPICE® (ASPICE) is a standard framework for designing and assessing automotive software development processes. Effective implementations lead to better processes and better product quality.

STAY ON THE CUTTING EDGE OF PCM DEVELOPMENT

Innovations in the automotive industry, such as ADAS and hybrid electric vehicles, as well as continuing efforts to reduce fuel consumption and emissions and increase safety, will result in progressively more complex PCM embedded software. Designing such PCMs is possible only by using innovative, industry-leading hardware and software development tools.

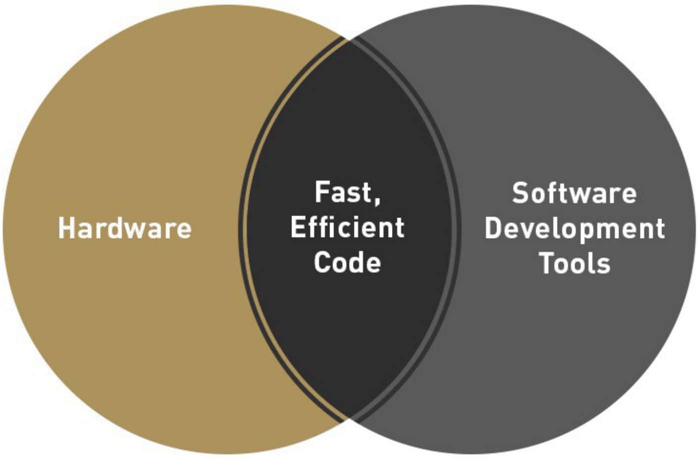

Figure 3: High-quality hardware coupled with tightly-integrated compilers produces fast, efficient code.

Global regulations and ever-shrinking budgets are prompting PCM application designers to choose cost-effective, high-performance, well-aligned powertrain system solutions. Using hardware and software development tools that are tightly integrated and highly secure can help you overcome PCM design challenges and stay on the cutting edge of powertrain innovation, including managing hybrid electric vehicles and providing OTA PCM updates.

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