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Improvement of powertrain mechatronic systems for lean automotive manufacturing

P. Chiabert [a], G. D'Antonio [a*], J. Inoyatkhodjaev [b], F. Lombardi [a], S. Ruffa [a]

[a]*Department of Management and Production Engineering, Politecnico di Torino, Torino, Italy*
[b]*General Motors Powertrain Uzbekistan,Tashkent, Uzbekistan*

* Corresponding author. Tel.: +39-011-090-7295; fax: +39-011-090-7299; *E-mail address*: gianluca.dantonio@polito.it

Abstract

In recent years, the increasing severity of emission standards forced car manufacturers to integrate vehicle powertrains with additional mechatronic elements, consisting in sensors, executors and controlling elements interacting with each other. However, the introduction of the best available ecological devices goes hand in hand with the legislation and/or limitations in different regional markets. Thus, the designers adapt the mechatronic system to the target emission standards of the produced powertrain. The software embedded into the Engine Control Unit (ECU) is highly customized for the specific configurations: variability in mechatronic systems leads to the development of several software versions, lowering the efficiency of the design phase.
Therefore the employment of a standard for the communication among sensors, actuators and the ECU would allow the development of a unique software for different configurations; this would be beneficial from a manufacturing point of view, enabling the simplification of the design process. Obviously, the new software must still guarantee the proper level of feedbacks to the ECU to ensure the compliance with different emission standards and the proper engine behavior. The general software is adapted to the powertrain: according to the specific target emission standard, some control elements may not be necessary, and a part of the software may be easily removed.
In this paper, starting from a real case-study, a more general methodology is proposed for configurations characterized by different powertrain sets and manufacturing line constraints. The proposed technique allows to maintain the accuracy of the control system and improve process efficiency at the same time, ensuring lean production and lowering manufacturing costs. A set of mathematical techniques to improve software efficacy is also presented: the resulting benefits are enhanced by software standardization, because the design effort may be shared by the largest possible number of applications.

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1. Introduction

Mechatronic components have been first employed in automobiles in the 1970s, when the electronic voltage regulator and electronic ignition were introduced. The employment of mechatronic systems increased over time, with particular concern for engine management and control [1]. Today, mechatronic still represents a significant growth area in the motor vehicle branch, even if many engine and safety systems are considered standard equipment in vehicles [2]. The reason for this trend is twofold: on one side, customers require automobiles equipped with high efficiency and low fuel consumption engines; on the other side, as the number of vehicles in the world increases, stricter emission standards are necessary to reduce pollutant emissions [3]. Furthermore, electronic components are usually lighter than the mechanical components they replace, leading to lower fuel and power needed. However, customer satisfaction is not the only target in the development of mechatronic systems; they also must be implemented into the manufacturing processes in an efficient way, with minimum costs for the manufacturer.

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The general configuration for an engine management control system is shown in Figure 1. The Engine Control Unit (ECU) is in charge of combustion optimization. It receives a set of electric signals from the sensors, which collect information to assess the current state of the engine. The quality of measured data is the result of a compromise among sensors cost, precision and reliability; further, several quantities like torque or emission concentrations are not measurable because of high measurement cost or short life of the data; hence, the ECU has to extract information from indirect measurements [4]. Data are analyzed by the ECU embedded software, which also includes a model of the engine operating conditions; the result of ECU calculation is translated into a new set of electric signals transmitted to the actuators, which determine engine behavior [3,5]. Mechatronic systems ensure benefits compared with merely mechanical frameworks, including higher engine performance and reduced risks for engine damages [6]; such systems are also able to adapt the fuel injection strategy according to the current state of the engine, taking into account, for example, the warm-up phase or the regeneration of particulate traps [5].

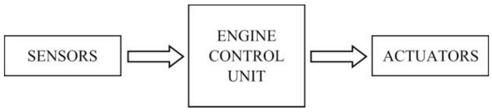

Fig. 1. Interconnection of engine mechatronic components.

The improved engine calibration reduces pollutant emissions; moreover, electronics allow to calibrate and control engine functional parameters in order to comply with different emission characteristics. Actually, the prescribed standards for pollutants produced by passenger cars exhibit large differences according to the specific regional markets; hence, worldwide production lines are required to assemble engines with different emission requirements, and the introduction of the best available devices is strictly tied to the legislations holding in the different target markets.

In this paper, we consider the case-study of a plant for car engine production, located in Central Asia; these engines are installed on vehicles sold mostly in CIS countries and on Uzbekistan market. On the Russian market, the Euro 4 standard is currently holding, but conformity to Euro 5 will be mandatory from 2015. In Uzbekistan, the compliance with the Euro 2 standard is currently mandatory, and no additional restrictions are expected.

The employment of mechatronic systems enhances the flexibility of an already developed engine: a flexible monitoring and control system would allow to comply with different emission standards, thus making an engine available for different countries. The adaptation of this system may also allow a manufacturer to extend the production of an existing engine, even if new restrictions on pollutant emissions are prescribed. For example, the introduction of a Diesel Particulate Filter (DPF) allows to easily reach Euro 4 prescriptions, while the installation of an Exhaust Gas Recirculation (EGR) valve on gasoline engines is necessary to comply with the Euro 4 standard.

Unfortunately, in many cases, the ECU software is highly customized for specific applications; it is adapted to the specific platform, the target emission standard, and the employed set of sensors and actuators. This customization occurs because designers adapt the set of mechanical components to the specific application, and rarely reuse an existing engine control system; the software is, in turn, adapted to the employed hardware. This application-oriented approach leads to disadvantages: a single change in the requirements or in the employed system may lead to a completely new software development. Additionally, the software must be redesigned when a new vehicle is developed, even if the hardware set exhibits small variations and the target emission standard does not vary. According to [7], the R&D cost of an engine control system for a diesel passenger vehicle is approximately 14 million dollars. This amount of money includes the combustion optimization phase (design of mechanical components and of engine algorithms), the emission testing of the whole system (engine, after-treatment, and ECU), and the development of new models for the ECU.

The aim of our work is to propose a methodology for the identification of a general formulation of the software embedded into the ECU: the replacement of an application-oriented approach with a functional-oriented one may allow to use the same software on different configurations, enhancing its flexibility, with several advantages for the manufacturer and no quality loss for the customer. In an additional step, we will propose a methodology to develop new ECU models and improve the efficacy of the algorithms.

In Section 2 we will introduce our case-study; in Section 3 we will present the two steps of our methodology. In Section 4, we will explain which are the main advantages of the proposed approach in a lean manufacturing perspective. Finally, in Section 5, we will discuss the impact of this work and provide some hints for future extensions.

2. Case-Study

In this paper, we consider different configurations – currently manufactured – of a four cylinders, gasoline 1.5L engine. In the following, in place of the real names of car models we simply use the tags “Car A” and “Car B”. The engine has been installed on Car A since 2011, and complies with the Euro 2 and Euro 4 standard. Two years later, Car B was updated and the same engine was adapted to this platform, proposed both in the Euro 2 and the Euro 5 versions. The employed sensors are the same in all the cases; conversely, there are some differences in the sets of actuators: the EGR valve is not used onto the Euro 2 vehicles, and other components, including the ECU, change with the platform. Finally, different software have been developed for these configurations. In Table 1, a subset of sensors and actuators is reported: different letters represent different components.