ACTIVE LEARNING CONCEPTS APPLIED ON A AUTOMOTIVE MECHATRONIC SYSTEM

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ABSTRACT
Nowadays, managing the combustion engines by the usage of electronics, has become indispensable. Without the electronics in this management system, would not be possible, for example, achieving the low emissions required by the environmental agencies, and meet, at the same time, the torque and performance requirements, imposed by the vehicles manufacturer. Study how the electronic management controls, the entire cycle of the engine operation, in different operating conditions, is a major challenge. To become this task easier, some small individual control loops are engaged (air intake, fuel injection and spark ignition), providing a support to the macro engine control. This paper aims to demonstrate a detailed procedure, step by step, to design a controller using the classical concepts of control systems, applied on a gas pedal + throttle body + electronic system, known as drive-by-wire system (DBW). The study proposed here becomes an important tool to support management engine classes and also classic control classes, for the students of Technology and Engineering Automotive, Mechatronics or Electric courses, because it demonstrates a practical application of mechatronic systems concepts involving multidisciplinary topics.

KEY WORDS
Drive by wire, Control, Vehicle, Embedded electronic.

1. Introduction

In the automotive area, embedded electronics is an item increasingly present and in constant growth and technological innovation. This growth is found in different parts of the car, whether the engine management, the brake system, comfort and convenience systems, etc. New embedded systems projects usually have their onset, on average, two to three years before the launch vehicle on the market, allowing you to do several tests on the proposed prototype [3].

The technology is often imposed by regulations and laws and sometimes simply by requirements and market issues. Traditionally, embedded electronic systems are first launched in the line of commercial vehicles to later be adopted by passenger vehicles. As an example, we can mention the monitoring and tracking of trucks systems (through GPS technology (Global Positioning System) and GSM (Global System for Mobile Communications)) which will also be adopted by passenger vehicles from the embedded structure in trucks [1].

This growing demand for new automotive systems generates the same time, an increasing need for new skilled professionals to operate these systems [5] because the concepts used in automotive systems end up being multidisciplinary, demanding it a solid knowledge from professionals, major foundations in the field of electrical engineering, chemical engineering, mechanical engineering and materials engineering.

Among these technologies, you can mention the electronic management system of the combustion engine, popularly known as electronic fuel injection. The management system has become an essential item today, providing not only a more efficient control on the emission of pollutants, but also a significant improvement in fuel consumption and engine performance in general [5].

Traditionally and for many years, the connection between the throttle and the throttle body valve, which controls the air to the engine inlet from a mechanical linkage was performed by a steel cable [6]. Furthermore, there was a presence of an idle actuator to maintain the engine at a low speed previously specified in the development of motor [9].

With the advancement of automotive electronics, especially in the electronic management system, represented here by the electronic injection as a whole, including sensors and actuators to the management system caused the engine of the car pass to be considered a mechatronic system. A good example which may be mentioned is the changes at the throttle valve; the inclusion of the DC motor coupled to a gear system and a position sensor (called a TPS - Throttle position sensor) allowed the elimination of valve opening system by steel cable (mechanically) as well as actuator idle [6], and this new set designated as Drive by wire system, or simply DBW [11].

The DBW system is an important development in the electronic management of engine system, as the inclusion of a mechatronic device for opening / butterfly valve closure allows the electronics of the car center (ECU) control, more accurately, not only the amount of air admitted to the engine as well as its idle since the angular
opening of the valve shall be determined by the mechatronic assembly formed by the DC motor, gearbox and TPS sensor [11].

Due to these particular features partially described the gear system, develop a control closed loop system for the DBW together using only the classical concepts of control, it is a challenging task, as evidenced by numerous articles that have difficulty in obtaining the mathematical model and for its high nonlinearity, as observed on [6], [8], [10] and [11].

The implementation and development of classical control systems is traditionally a challenge to the students of the courses of which discipline is an integral part of the curriculum. In current projects of educational processes in engineering, the passive format is the most used in the process of teaching and learning, where information is passed by the teacher using "chalk and talk", and research in education demonstrate its inefficiveness [12].

Originally, the act of teaching in engineering used to have very close links with the practice of engineering, but gradually, this act began to use more and more theoretical and less practical classes [12].

The most modern teaching and learning techniques use the concept of active learning and project-based learning. These techniques suggest that a student is to be primarily responsible for acquiring knowledge, where the teacher becomes just a facilitator in the process of teaching and learning [12]. Thus, the student shall be encouraged to discover the phenomena related to the discipline in question and associate them with situations or real-world systems, and contribute to the development of important skills for a professional engineering, such as sustainability, social responsibility, teamwork, among others [2].

Precisely because of the difficulties observed in the control subjects and, considering the strong practical appeal that a control system applied to a car has, this paper will address a practical, clear and extremely didactic, the development of control system projects by students using the concept of active learning foregoing. It is hoped that this, students can feel more encouraged with the practical development and ease of obtaining results from the use of teaching kit, as supporting elements and facilitators for teaching.

2. The DBW Experimental Set

The DBW system, as previously mentioned, is an important development in the electronic management of engine system, since its inclusion has allowed electronic automobile plant (ECU) to control, in a more precise way, not only the amount of intake air the motor, but also its idle since the angular opening of the valve shall be determined by the mechatronic assembly formed by the DC motor, the gearbox and the TPS sensor [11]. It is also considered as an important actuator within the internal combustion engine, being a key element for controlling the power and rotation torque motor [10]. The mechatronic assembly described in this paragraph and used in the experimental setup is shown in Figure 1a and 1b.

In addition to the throttle body shown in Figure 1a, the experimental set developed for the design of the proposed study, contains the accelerator pedal and electronic circuits, basically formed by operational amplifiers and power transistors. The experimental set used in this study, is exactly the same set used in the work proposed by [5] (positioner assembly), where Figure 2 shows the block diagram.

![Figure 1a – DBW Block Diagram.](image_url1)

![Figure 1b – VW Polo DBW Throttle Body.](image_url2)

![Figure 2 – Experimental Set Block Diagram.](image_url3)

The signals $R(s)$ and $H(s)$ shown in the Figure 2 block diagram, have a maximum variation in amplitude in the range of 0 to 10V, and configured properly adjusted by conformers circuits 1 and 2. Therefore, the signal $E(s)$ will produce a consistent variation with input signals $R(s)$ and...
Finally, there is in Figure 3 the developed positioner assembly [5].

Figure 3 – Experimental Set.

### 3. Methodology

To evaluate the dynamics involved in the systems under study in a simplified form, open loop tests are carried out through excitations of the step type, and observing the dynamics in the desired output variable. In the present work, the system under study is the butterfly valve, where the steps were applied to the PWM driver (Pulse Width Modulation) and the transient response of the system observed by measuring the signal provided by the TPS sensor. As support for this initial stage, we have used a data acquisition system installed in a computer, comprising a plate and an elaborate acquisition software Matlab / Simulink, with connections shown by the Figure 4 block diagram.

Figure 4 – Block diagram to obtain \( P(s) \).

This preliminary test allows identification by the student's mathematical model \( P(s) \) representing simplified, the butterfly valve DBW system. Using the information collected by the data acquisition system, various graphs were generated, as the example shown by Figure 5, which from the qualitative observation of the displayed response, enables to choose the transfer function

\[
P(s) = K \frac{as + 1}{bs + 1}
\]

as applying to represent the plant because, although the amplitudes and the time constant are not the same for all graphics, the standard response was maintained.

The structure of the transfer function \( P(s) \) of choice is students' prior knowledge and represents a transfer function of a filter type advance or phase delay, depending on the relationship between the factors \( a \) and \( b \).

For the identification of the parameters \( a \), \( b \) in each experiment, the students do the simulation of \( P(s) \) transfer function, with the support of Matlab / Simulink software, and the parameters are adjusted iteratively observing the experimental graphic with simulated graphic in order to reduce the error between the approximate mathematical model and the actual dynamics of the physical system. Since the value of the gain \( K \) is obtained immediately by the relationship between steady-state output value relative to the magnitude of the step applied to the system input.

The maximum and minimum variations of the parameters \( a \), \( b \) and \( K \) obtained in the different performed experimental tests are presented in Table 1 and, making an average of the values found, one comes to the transfer function \( P(s) \) approximate to

\[
P(s) = 0.1 \left( \frac{s + 6}{s + 9} \right)
\]

Table 1. \( K \), \( a \), \( b \) parameters range.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>( K )</td>
<td>0.05</td>
</tr>
<tr>
<td>( a )</td>
<td>0.12</td>
</tr>
<tr>
<td>( b )</td>
<td>0.07</td>
</tr>
</tbody>
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responsible for representing all possible plants. It is known, therefore, that the closed loop system shall tolerate variation (uncertainty) of the integral parameters of the simplified transfer function \( P(s) \). This allows you to include in the discussion, the issues of bank stability (phase margin and gain margin), although these issues are not detailed in this article.
The plant behavior analysis $P(s)$ closed loop is made through the Locus of Roots - LGR (see Figure 6), using a purely proportional controller, as a first attempt.

It is shown that there are two difficulties associated with proportional control only observing Figure 6: The first difficulty is the observed absence of an integrator in the structure of the approximated transfer function $P(s)$. In classic control, the absence of integrators in the plant carries a low gain at low frequencies, causing an error in regime between the $R(s)$ and $C(s)$ (Figure 2), known as steady-state error or error final value [7]. This error in the particular case of the butterfly valve in the engine application, will be responsible for producing a rotation in the lower motor to desired by the driver and imposed by the accelerator pedal. The second difficulty is related to the response speed of the DBW together. The time constant of the closed loop system response is enforced by the locus of the closed loop pole, the largest allowable constant passage time is $1/6$ [s] when the controller gain tends to infinity.

Again relating to the practical application of the system, the response speed or valve opening is directly dependent on engine management strategies imposed by the ECU. Current strategies employ a management by torque and also depending on the cubic capacity of the engine who's which the DBW system is installed. Therefore, allow it to be possible to change the response time constant is extremely important.

To satisfy the two requirements at the same time described above, it suggests the inclusion of a compensator, comprising a pole and a zero at the origin, but closer to the origin as the zero plant, having the structure

$$G_C(s) = K_C \left( \frac{s + z}{s} \right)$$

where $G_C(s)$ depicts the structure of a proportional integral compensator type, also known as PI compensator.

The compensator pole at the origin contributes to the minimization of the final value and the error compensator zero position, with the constant $K_C$ change the response time constant. The resulting LGR inclusion PI compensator proposed that the plant $P(s)$ is shown in Figure 7.

As the structure of the compensator PI presented, is also a classic structure and easily built with the support of an electronic circuit formed by operational amplifiers, the project developed, tested and validated by students in a simulation environment, is put into practice in the positioner assembly according to the control theory. So, to perform the necessary comparisons between the simulating the practical results of the positioner, with and without the PI compensator, develops a sense and critical analysis on the students.

4. Conclusions

From the difficulties observed on the Classic Control subjects, combined with the existing practical and visual appeal of automotive systems, this study demonstrated, in a practical way, the development of a control design and compensators tuning, using the concepts of active learning.

The DBW assembly was first identified through a simple characterization (step response), thereby eliminating the large volume of calculations that the step of mathematical modeling requires. Students are responsible for identifying the parameters of the approximate transfer function, combining experimental results with simulation results.

Furthermore, the simulations allow the development of the students in a computing environment and in practice with the physical design mounting part too. The responses obtained with the DBW system, with and without the PI compensator, could be easily visualized without the need of using a benchtop application, such as oscilloscope, just by observing the valve range opening.
References


