Mechatronics and automotive systems design

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Abstract As the complexity of automotive vehicles increases, so does the need for high calibre, multi-disciplined engineers. This paper provides a discussion into the type of control systems found in modern automotive vehicles and the skills required by the engineers working in this mechatronic system environment.

Keywords automotive systems; mechatronics

The motor-car has evolved over the years and most cars on the road today incorporate automatic computer control of the vehicle mechanics.[1] This type of system is a good example of a mechatronic system[2] and can be noted by the complexity of operation, consisting of a large number of sensors and actuators under computer software control. Such an arrangement has a very pronounced effect on the vehicle dynamics. The purpose of adding this complexity to the design and manufacture of the vehicle is to improve the vehicle performance, with the 'improvements' considered by the end-user requirements. Additionally, depending on the system requirements, these may be considered to be 'simple', but still involve overcoming mechanical, electrical and control problems, or termed 'safety critical', and so are required to have redundancy and advanced failure mode analysis built-in. The move towards increased electronics within the automotive system overall is a response to legislative requirements such as emissions, and more stringent safety demands (ABS, ESP, airbags, etc.), as well as demands for new features (heated seats, climate control, etc.). This results in a need for active or intelligent control of vehicle functions.

Advances in automotive control systems increase the need for highly skilled engineers capable of designing these control systems. These advances in turn led to an increase in the requirement for engineers to be able to use modern rapid prototyping tools to reduce the time taken to model and develop the control systems. With the continuous increase in the complexity of automotive vehicles, the need for high-calibre, multi-disciplined engineers needs to be met with suitable education.

This paper describes the type of control systems found on modern automotive vehicles and the problems faced by engineers developing the embedded control systems. The paper then describes the development process, and discusses the skills required by the engineers and the similarity of these skills to those of the 'mechatronic engineer'. The paper concludes with suggestions for the education that these engineers need to ensure they are best educated for automotive control system engineering.

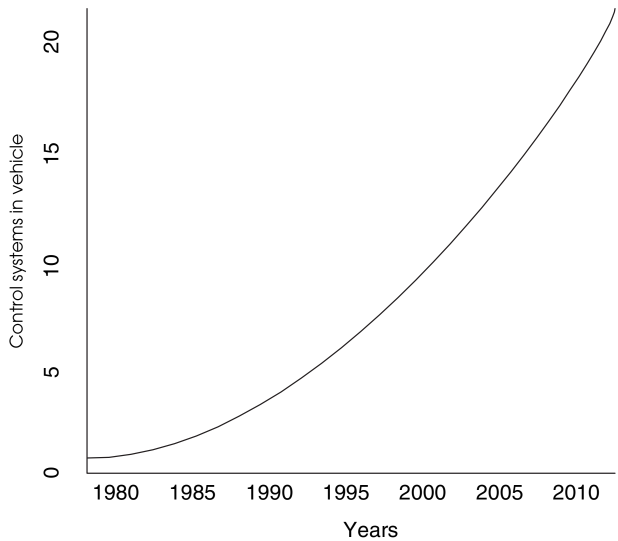

Fig. 1 *Increase in embedded control systems.*

Automotive electronics

The use of electronics in automotive systems has changed radically over the last 25 years.[3] The electronics are now required to implement a range of operations, including automatic control system functions. Figure 1 (taken from Ref. [4]) shows the dramatic increase in the number of control systems within the automotive system, with each control system required to operate to a strict specification and to operate robustly in a demanding application. The early electrical system arrangement that existed in the automobile consisted of basic wiring technologies that supplied power to various vehicle systems. The electrical system on the vehicle was only made up of switches, wires, relays and controlled motors or lamps. Modern vehicles however, incorporate a range of sensors and actuators that have a different set of requirements. Alongside the high-power electric circuits controlling for example heated windows or heated seats, there are very low level, high bandwidth signals for data communications such as data from knock sensors or CAN[5] data.

The modern automotive electrical/electronic engineer now has to deal with a wide variety of electronic system designs and has to develop vehicle electrical systems to strict specifications. These specifications are mainly concerned with the environmental properties of the electrical system. For example, they define the operating temperature range, radiated EMI (electromagnetic interference)[6] emissions, and EMI susceptibility. Legislation has defined a standard to which vehicle electronics are designed, but vehicle manufacturers also utilise their own set of specifications, most of which are very much more stringent than are required by the legislation. For example, the European standard for susceptibility for vehicle-mounted electronics[7] is 30 V per m, but many vehicle manufacturers define their limits at over 100 V per m.

Cost aspects are also a key concern in the design decisions undertaken. In order to reduce the cost of these systems, many are now integrated with each other, sharing input and output signals. As an example, the Electronic Stability Program (ESP)[8] system is integrated with the anti-lock braking system (ABS). This however increases the complexity of the control system design and further relies on good design practice, with designers using simulation techniques to validate ideas prior to prototyping and manufacture. The simulation models need to model all eventualities and perform extensive Failure Mode Analysis (FMA). Vehicle manufactures also have the need to increase the 'desirability' of their vehicles and to achieve this, they have to increase the features of their vehicles whilst maintaining compliance with legislation . . . all this is required with no extra or even reducing the cost of the vehicle.

The electrical system on a modern vehicle is highly integrated with the mechanical system and much of the electronics on a vehicle control mechanical parts. The simplest example of this is probably the electrically operated window. Although on the surface an electric window consists of just a switch and motor, safety and security requirements make this system much more complex. The window, for example, has to be able to stop moving if an arm or finger is trapped in the window and yet still close or open in the winter when the glass might be frozen and the motor has to provide a large power to move the window glass. It also should close if the user locks the vehicle via central locking, thus it needs to be integrated with the central locking system.

Other systems are very much more complicated, e.g. an electronically controlled differential (Fig. 2) will have many sensors and actuate (either directly via an electric motor or indirectly via a hydraulic system) a clutch which controls the amount of slip across the differential. The control for this system not only has to take inputs from the driver and status of the vehicle, but also has to operate knowing the status

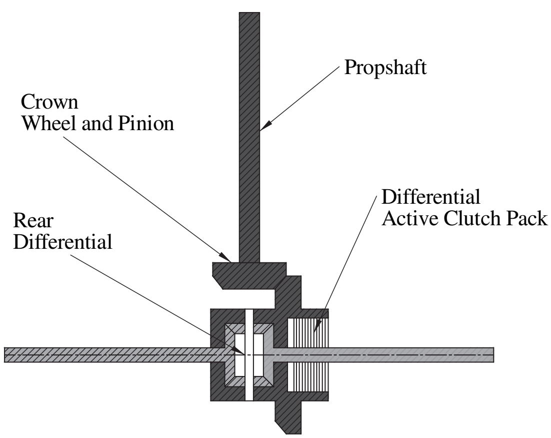

Fig. 2 *Electronically controlled differential.*

of the mechanical parts of the differential. For example, is the clutch overheating? The challenge for the designer of such a system is to combine skills in the operation and limitations of mechanical systems, in electronic design, and in control theory to provide e.g. the clutch or hydraulic actuator; suitable drive and input signal conditioning electronics; and a control algorithm.

These mechatronic systems are becoming increasingly important to the vehicle manufacturer and are changing the way in which vehicles are designed. Many of the compromises that purely mechanical systems have can be overcome using mechatronic design approach, and this provides the enhancements many of the vehicle manufacturers require. This in turn means that the role of the automotive electrical engineer is changing. Twenty years ago, they could have been a pure electrical engineer, 10 years ago they needed electronics capabilities, now, and increasingly so in the future, they will need to have an understanding of mechanical systems and the control of such systems. Vehicle enhancements that are currently being developed and involve huge amount of mechatronics include, electronically controlled suspension using magnetically rheological fluids, stability systems using active differentials, and dual clutch transmissions.

Modern engineering methods

The types of systems encountered in an automotive environment are complex and require long development times. In addition to providing the control, systems that are used on vehicles have to comply with legislation and safety requirements defined by both the vehicle manufacturers and the countries in which the vehicle is sold. These requirements can be electronic, mechanical and functional. Functional requirements can take many forms and are often defined to ensure a safety standard. Active control systems must fail in a defined and safe way. In the example of an active limited slip differential, if the control system that is controlling the clutch in the differential should fail, the differential should release its clutches and the system should act like a conventional non-limited slip differential. Other functional requirements may involve other vehicle systems. For example any active control system that is controlling a limited slip differential should release the clutches in the differential if the ABS (anti-lock braking system) is activated, and for this action there are defined response times that have to be met.

Many vehicle manufacturers are looking at rapid prototyping to reduce the development time and therefore cost of designing such systems. Rapid prototyping involves designing a control system using a CAD package that allows the user to simulate the various elements of the control system. The most widely used CAD package that is used is from The Mathworks[9] is Simulink,[10] part of the MATLAB suite of development tools. Simulink allows the user to draw the control system and simulate the control system before the hardware is created and control algorithm coded. This visual representation of the control algorithm is called the control model. Models can be created to represent the mechanical and vehicle elements of the control system and these too can be simulated. These are the plant models. When the control algorithm is thought to be correct the control model is then auto coded in to ‘C’ source code. It is then complied in the conventional way and downloaded to an electronic controller. The electronic controller is then connected to the vehicle and the control system tested and calibrated on real world hardware. If changes need to be made to the control model, these can be done using Simulink and, either the model is tested by simulation, or the control model is auto coded and downloaded once again to the ECU.

Depending on the control system and the company, any number of engineers could be working on the project. It is not uncommon for one person to be responsible for delivering the entire control system, and this one person may have to define the system specification, model and develop the control algorithm, and test the system on the vehicle. This requires a very high calibre of engineer.

The role of the mechatronics engineer

Automotive manufacturers have in the past employed both mechanical and electronic engineers each with their own well-defined capabilities. These engineers worked together but rarely got involved with each other’s activities. As described previously in this paper, modern vehicle system requirements increase the need for cross discipline engineers who have an in depth understanding of both mechanical and electronic systems. Engineers will often have to design a control system from a blank piece of paper, specifying both the mechanical and electronic components. They will then have to do the entire computer modelling of the control system and implement it on the vehicle. Pure mechanical engineers usually design the mechanical parts of the control system. But the control system engineer will need a thorough understanding of the mechanical parts so they can be modelled correctly in the control algorithm development. They will also need to be able to design advanced electronic circuits to actuate the new types of actuators currently in development, write control software to control these actuators and have a complete understanding of the mechanical system they are controlling.

The automotive control system engineer role is ideally suited to an engineer with mechatronics training. Many of the control engineers working in automotive engineering have their educational background in mechanical engineering and often only specify the requirements of the ECU to be used on a control system. This means that they do not have to design the electronics used. But, when the system is being tested and commissioned the controller needs to also be tested and this is often done in isolation. This task needs an in depth knowledge of electronic principles and again this is something to which a mechatronics engineer would be very well suited.

As vehicle control systems become increasingly common, the need for well-trained mechatronic engineers will also increase. Vehicle manufacturers are reducing the size of their work forces and looking at other ways in which they can reduce their costs. Reducing the size of their design teams whilst increasing or not reducing the skills is something they are very keen to do. This makes the prospect of a multi disciplined mechatronics engineer even more interesting, but this puts a lot of responsibility on the mechatronics engineers and these engineers have to have a very high level of skill.

Mechatronics in education

The mechatronic engineer is an ideal solution to the problem faced by vehicle manufacturers but there are very few engineers of this type available. This is mainly due to a lack of courses and students are not encouraged to move in to this field. Mechatronics courses need to be marketed in a different way, making them more attractive and, although they are seen to be a difficult course students need to be aware of the rewards and the knowledge that manufacturers have difficulty in finding these types of engineers. In automotive engineering, engineers with a mechatronics capability are very highly respected and can command high salaries.

For an automotive application, the ideal mechatronics course would encompass mechanical design incorporating hydraulic theory, electronics design incorporating analogue, digital, microprocessor, mixed signal and EMC theory, and a thorough understanding of control theory. Mechatronics is a highly skilled discipline and although the training should involve a high level of theory practical experience is also needed. This practical training is best given through projects where engineers can work together as a team especially with external engineers. Many manufacturers have projects that would be ideal for mechatronic students and would give the students a valuable experience of working on real life control systems. These projects can be allocated to students similarly to in industry, providing the students with the experience of working to deadlines and with project management.

Conclusions

This paper has described various control systems which are currently available or in development on automotive vehicles and shown these control systems to be true mechatronic systems. It has described the modern design methods that vehicle manufacturers use to develop these control systems and the ways in which the design engineers have to work to carry out this development. From this, the need for highly skilled mechatronic engineers is realised. This paper concludes by describing the training that these mechatronic engineers require from educational establishments.

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