

by **Kedar Godbole** and **Brian Fortman**

Texas Instruments

DSP Technology Makes Cars Fuel Efficient And Smarter

The role of digital signal processing in modern automobiles and how it is shaping the fuel-efficient and smart car of the future.

Increasing automotive fuel efficiency is key to lower fuel costs and meeting the increasingly strict emissions standards. Engine design and reduction in the weight of the automobile are two important factors for reducing fuel consumption. As newer technology becomes

available, it allows automotive manufacturers to re-examine the fundamentals of product design. Inexpensive, high-performance digital technology now available can create a quiet revolution. Automobiles that incorporate this innovative digital technology are "smarter" than ever

before and, thus, are more fuel-efficient, safer and more comfortable.

EVOLVING APPLICATIONS

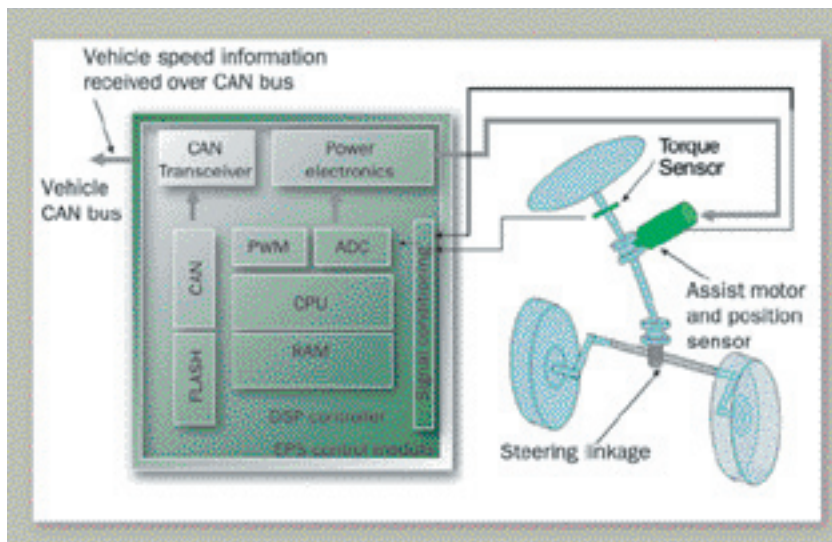
As auto manufacturers innovate, several systems are currently undergoing a transformation. Electric power-assisted steering (EPAS) and integrated starter alternator (ISA) are two examples of technologies finding their way into vehicles, which demonstrates how powerful new digital signal controllers are transforming the automobile.

In a hydraulic steering system, the hydraulic pump, commonly known as the front-end accessory drive, is powered off the engine and is constantly running. This creates a significant drag on the engine. Switching to an electromechanical model, where an electric motor produces the steering assist torque, results in the elimination of this parasitic drag and boosts fuel economy. In addition, elimination of the fluid reservoir, pump, hoses and the heat exchanger to cool the power steering fluid reduces a significant weight, further improving fuel economy. Estimates for this improvement in fuel economy are generally in the 3% to 5% range. Switching to an electromechanical steering assist also improves the reliability of the vehicle and cuts maintenance requirements.

An overview of such an electric power-assisted steering system is shown in Figure 1. An electric motor, most frequently a permanent magnet synchronous motor (PMSM), is used to generate the steering assist torque.

At the heart of the system are two vital components: the torque sensor and an EPAS controller, most often implemented with a powerful digital signal controller. The torque sensor senses the driver torque (i.e.,

Figure 1. Overview of an electric power-assisted steering system.



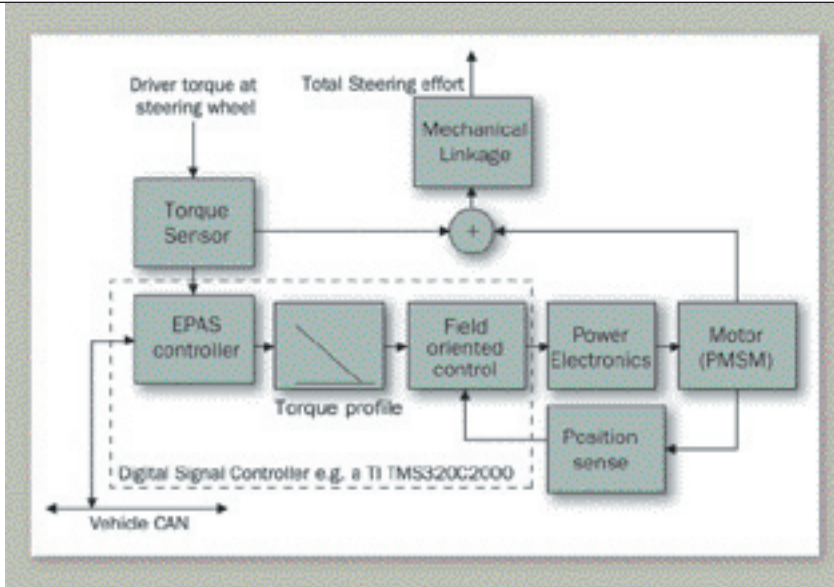


Figure 2. Control scheme of the electric power-assisted steering system.

whether the driver is steering left, right or not applying significant torque at all). The control loop then acts as a torque amplifier, with a gain that is determined based on speed. At low speeds, the maximum assist is provided, while at higher speeds the assistance is tapered off. The exact nature of this profile is usually customized to the vehicle characteristics such as weight and customer preferences. The EPAS controller gets the vehicle speed information from one of the other control modules in the car, such as the engine control module (ECM), for example, over the controller area network (CAN) bus. The EPAS controller then translates this to a torque command to a motor control algorithm.

PRECISION MOTOR CONTROL

In order to provide a smooth response as the driver steers the car, it is critical that the motor produces a constant torque with the least possible variation in torque as the motor rotates, known as torque ripple minimization.

To accomplish this, it is necessary to maintain a 90 degree angle

between the stator and rotor flux, and maintain this relationship as the motor rotates. To maintain the alignment, two things are needed. First, it is necessary to know the rotor flux position, and second, establish a (fictitious) stator current vector, which creates a magnetic flux vector. In this type of control, measured motor currents are translated to a coordinate system that is synchronous with the rotor flux vector. This type of control scheme is known as a vector control scheme, and a block diagram for a permanent magnet synchronous motor is shown in Figure 3.

Referring to Figure 3, the control algorithm sets up a current loop around the motor in order to establish the stator magnetic vector at a desired angle. The measured currents are transformed from the stator aligned coordinates to a rotor flux referenced frame. This allows effective control of the torque generated. Once the control algorithm (most frequently a PI control law) determines the voltage command, based on the desired currents and present value of currents, this voltage

command is translated back to the stator coordinates. Pulse width modulation then transforms these voltages, and a high-power inverter completes the drive system. Once the so-called current loop is closed, an outer loop controls the torque generated and speed at which the motor rotates. The position feedback is obtained from a position sensor, or the rotor flux position can be estimated by running an estimator. In an EPAS application, a high precision position sensor such as a resolver is used, resulting in a closely controlled torque, with the end result being smooth steering operation for the driver.

Until the advent of modern day DSP-based digital signal controllers, the implementation of such field-oriented controllers has historically been restricted to either large motors or for very high performance applications, owing to the numerically burdensome nature of the computations that need to be performed in real time.

WASTE NOT, WANT NOT: ISA

The starter and alternator have opposite uses—one as a motor for turning over the engine, the other to generate electrical power. Since a motor and a generator have a similar structure, it is possible to use the same physical component as both a starter and a generator. The key to making this possible is the capability to manage the power flow effectively.

A high-performance digital signal controller enables this transition, resulting in the creation of an ISA system that provides each function when it is needed. The integrated starter alternator is smaller and lighter, resulting in better fuel economy. But it gets even better—an intelligent ISA system can manage the amount of energy being converted into electrical power

and can act as a regenerative brake. Thus, it can turn the car's kinetic energy into electrical energy, which can be reused. This not only results in saving fuel, but also reduces wear and tear on the brakes. This improved system results in better vehicle reliability and lower cost-of-ownership for the consumer.

Both these applications need precision real-time control of the electrical motors and generators to enable manufacturers to create the systems.

To accomplish these objectives, designers must ensure that the motor is used to the fullest extent and minimizes wasted power. Furthermore, because newer designs typically offer a growing feature set that fits into smaller spaces, designers also need a way to add features without adding components. The key to using the motor to its fullest is to understand how real-time control leads to optimal motor and system architecture.

IMPLEMENTING REAL-TIME MOTOR CONTROL

Digital signal processor-based controllers are enabling automotive manufacturers to design their EPAS and ISA controller modules with advanced techniques such as field-oriented control to overcome the traditional implementation challenges. Equipped with 32-bit, 150 MIPS modern motor control optimized DSP cores, enable designers to implement the reference frame translations and the control law implementations at high sample rates, which results in very high current loop bandwidths. The entire 32-bit FOC algorithm cycle with feedback can be performed in less than 10 microseconds, leaving plenty of processing headroom for flux estimators, and other advanced control techniques.

Modern motor control-specific

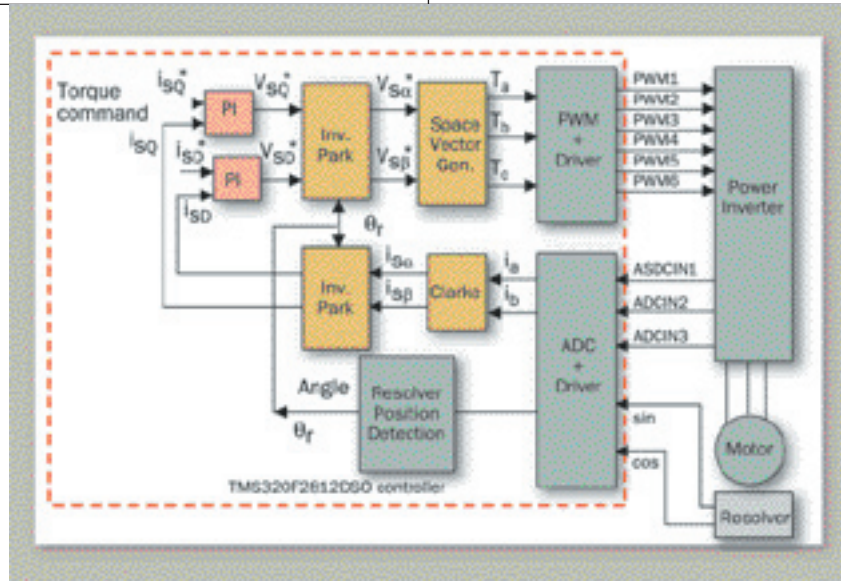


Figure 3. Field-oriented control of a PMS.

DSP controllers (for example, Texas Instruments' 32-bit, 150-MIPS TMS320F2812 digital signal controllers) are designed with key motor control peripherals on chip. Among these are on-chip flash memory, analog-to-digital converters (ADCs), pulse-width modulated (PWM) outputs and CAN bus controllers. In addition to providing high-quality DSP computational capabilities, they feature a number of innovations that combine DSP performance and precision with high-end microcontroller (MCU) flexibility.

Extremely efficient C compilers allow developers to create object code nearly as compact as native assembly. This makes it possible for the drive designer to focus on innovation.

Programmable digital signal controllers provide several advantages to the designers by allowing a common platform for quick deployment in variants, with flexible software that makes it easy to customize a platform for a particular vehicle.

The precision that the motor control enables the designers of

the power steering systems to optimally tune the characteristics of the system, such as flick responses, and control how much assist torque is provided at various speeds. Since an intelligent controller communicates with the engine control module (ECM), the ECM can send speed messages to the EPAS module, which then can control the assist torque depending on vehicle speed.

In an ISA, the motor controller can also do double duty by controlling the regenerative braking torque that increases the fuel economy. Another potential innovation is the use of the starter motor to add drive torque during peak acceleration.

FUTURE INNOVATIONS

Real-time motor control is already on its way into automotive systems, including EPAS, ISA and also in heating and ventilation blower systems. Looking into the future, real-time motor control enabled by digital signal controllers is also finding its way into control of the main drive motor in hybrid electric cars, and in pure electrical vehicles. Other real-time control appli-

cations are also benefiting from powerful real-time controllers, such as engine control and suspension control.

COMMUNICATIONS AND ENTERTAINMENT

Today, consumers are demanding increasingly sophisticated communications and entertainment throughout their daily lives. Likewise, car drivers are demanding more road and vehicle information for safe, reliable operation. High-performance DSPs can help provide these telematics and infotainment features by bringing easy-to-use wireless connectivity to the car. Advanced digital signal processing is essential to wireless communications, regardless of the type of network link.

Cellular phones and high-end audio systems are already based on programmable DSPs, and the trend to add functionality to these systems will depend even more on advanced signal processing in the

future. The eventual possibilities of DSP-based telematics and infotainment seem almost limitless, but it is not necessary to look into the distant future to see changes taking place in these systems. Today, the basic AM/FM radio with CD player, found in virtually all new cars around the world, offers manufacturers an important value-added opportunity for the use of DSPs.

A recent feature that is rapidly becoming standard is MP3 decoding, which is often implemented with a dedicated decoder chip. A programmable DSP, however, can support various audio decoding standards such as MP3, WMA and AAC, can be adapted as standards change and is capable of implementing even more features. For instance, on initial setup it can be used to enhance the audio system through automatic frequency balancing to match the acoustics of the space, improve the sound quality and, most important, the user experience.

Audio enhancement is only the

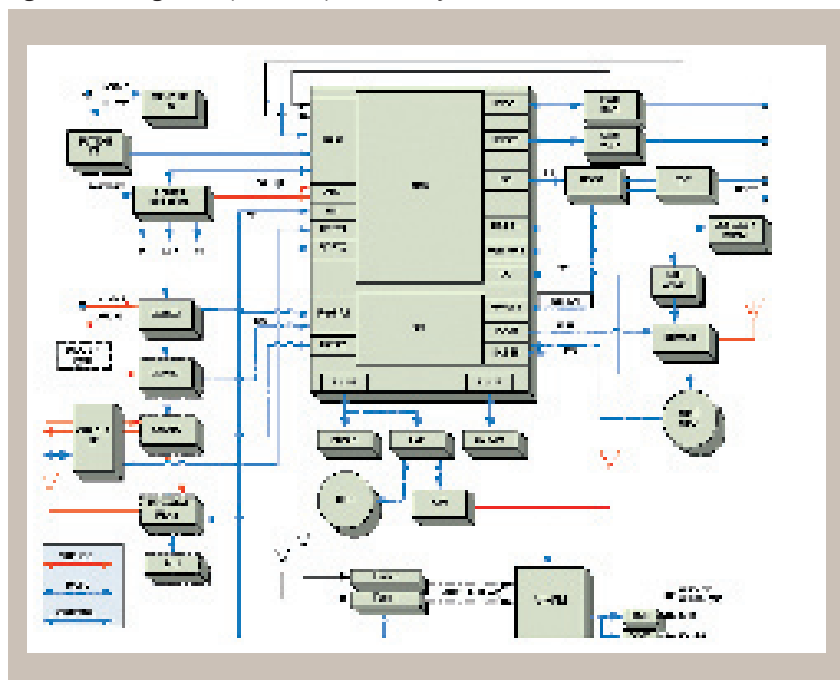
beginning. The same DSP can be used to support hands-free audio processing for cellular phones. Integrating a separate hands-free system into the vehicle could add hundreds of dollars to the sticker price of the car. But leveraging the existing DSP in the radio head unit to perform this processing would require little more than additional software and an integrated Bluetooth transceiver at a marginal increase in cost. The DSP, therefore, adds a great deal of wireless connectivity but helps keep products affordable while saving space and power.

DSP-enabled performance is essential for this type of system enhancement because of the echo cancellation and noise suppression that integrated hands-free kits require. DSPs also enable enhanced voice recognition used for safe, hands-free control of wireless connectivity, cockpit systems and media browsing. Once the consumer is using a robust voice activation system, the distractions of punching console buttons and viewing display information are eliminated. In addition, DSPs have the performance headroom required to add other types of communication services to the same system, including global positioning, navigation and information sharing with other systems in the vehicle.

Other developments are coming soon. Adding a hard disk drive to the audio system transforms it into an MP3 jukebox capable of storing an entire music library. The DSP performs MP3 encoding, MP3 decoding, CD drive control, block decoding and decryption of premium digital audio content. Eventually, as consumers come to expect more video transmission over wireless links and video storage in the vehicle, the DSP will be used to support video decoding as well.

Obviously, the systems being

Figure 4. A design example for a speech radio jukebox.



discussed here are complex and processor design must support different types of functionality efficiently. In many cases, it will be useful to divide the software functions of the system between a DSP and a RISC microprocessor, reserving signal processing for the former while the latter handles more traditional control tasks such as the network connectivity, file systems and user interface.

Voice recognition, in particular, works efficiently on an integrated dual-core processor in which the DSP core handles the front-end processing of the sound while the RISC core handles the lexical tasks. Figure 4 shows a design example for a speech radio jukebox. But whether the DSP stands alone or is integrated with a RISC, programmability makes it possible for a manufacturer to add features modularly. System software modularity not only saves development effort, but it also allows the manufacturer to develop a varied line of differentiated communication and entertainment offerings appealing to the economy, mid-line and luxury markets.

AUTOMOTIVE DSP SOLUTIONS

In the past, many designers considered DSPs to be a single, highly specialized kind of processor that was difficult to work with. Today, many types of DSPs are available that are designed to meet the needs of specific end applications. DSPs have become much easier to use, with in-depth development support that includes high-level language tools, familiar integrated development environments and extensive selections of off-the-shelf algorithms from third parties.

With DSPs that offer up to 900 MIPS of performance, handling the real-time signal processing necessary for audio entertainment,

as well as the encode/decode, noise suppression, and other real-time signal processing creates countless opportunities for hands-free cellular and Bluetooth wireless communications. A rich array of peripherals and memory configurations allow designers to target system needs accurately. For example, TI integrates DSP cores with 32-bit ARM RISC microprocessors in its dual-core OMAP™ line of processors, as a way to combine the high signal processing performance of DSPs with the general-purpose computing capabilities of a RISC core. Such processors extend the functionality of communication systems to include new multimedia applications with more robust features.

ENABLING FUTURE INNOVATIONS

Vehicle manufacturers need to know that the digital technology they are putting to work is stable and reliable. DSP suppliers with experience in the automotive industry understand these concerns and are producing specialized DSP controllers that are automotive Q100 qualified. In their product lines, DSP suppliers offer processing architectures, integration and packaging that effectively address automotive system-level issues of cost, reliability, performance and power consumption.

Automobiles have never been through a more challenging design period. Renewed need for low emissions and fuel consumption, combined with increasing demand for communications, entertainment and safety, compel car manufacturers to look to new digital control technology. Fortunately, DSP controllers provide the high performance and flexibility needed to implement new solutions that can take automotive systems ahead

into the new century. By enabling innovations such as EPAS, ISA and more extensive telematics and infotainment, DSPs can help cut vehicle weight, save costs, reduce gas consumption and exhaust emissions, and improve the travel experience for drivers and passengers alike. ■

ABOUT THE AUTHORS

Kedar Godbole joined Texas Instruments in 1998 after he earned his Master of Science degree in Embedded Systems and Control from New Jersey Institute of Technology. Kedar's focus was on high-performance servo control and using DSP-based techniques to control flexible structures. Since then, he has focused on DSP applications in digital control and is currently with the Digital Control Systems Group in Houston, Tx. His responsibilities include driving the Digital Motor Control Software Program and enhanced software reusability, deployability. He earned his B.E. Degree in 1995 in Electronics from the University of Pune, India.

Brian Fortman, worldwide telematics marketing manager, spearheads the Automotive Telematics and Infotainment space at Texas Instruments where he is responsible for new business development, product definition, marketing and customer programs. He joined TI in 1991 and has been involved with many business units within the company. Prior to working for Texas Instruments, Fortman was part of the sales and engineering offices at Johnson Controls Inc. in Saint Louis, Mo. He also worked in the IT Department of Monsanto Corp. also located in Saint Louis. Fortman received his Bachelor of Science in Electrical Engineering from the University of Missouri-Rolla.