New Challenges For Microsystems-Technology In Automotive Applications

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The need for safer, more comfortable, pollution-free and cost effective transportation has created a great opportunity for automotive electronic systems. These systems are deaf, dumb and blind without the use of sensors to provide their controllers with critical inputs to make intelligent decisions (or at least monitor dynamic conditions). The availability of MST to perform these sensing functions has become widely accepted in the automotive industry as the technology of choice in providing highly reliable, miniature, and cost-effective solutions to these current and future applications. This paper discusses some of the more interesting applications of MST and some of the challenges facing automotive systems engineers in the deployment of MST in current and future vehicle electronic systems.

Historical Evolution

With the invention of the automobile by Captain Cugnot in 1769, it was possible to travel a breathtaking 3.2 /km per hour. The spark plug was invented in 1902 by Robert Bosch. Safety and traffic organisation led to lights and indicators. In 1932 the first multi-media system entered the market - the AM and later the FM radio was the first electronic component built into cars (Idealwerke, now Blaupunkt). By the mid 50's, the automobile industry needed more electrical power for higher displacement engines which required additional ignition energy. The switch from 7 V to 14 V was accomplished in only two years. With cars now including numerous electronic systems as "standard" features, vehicle energy requirements have been increasing by four percent every year for the last twenty years. Ever since the introduction of the Manifold Air Pressure (MAP) sensor for engine control in 1979, followed by airbag sensors in the mid-eighties (introduction of the airbag system within a car in 1981 based on an electro-mechanical sensor system), microsystems have been increasingly used throughout the vehicle.
Applications including motor control systems, cruise control, the gear box, the control panel, the Antilock Braking System (ABS), safety systems, and interior electronics for comfort and entertainment.
But while the function is present, to the user the microsystem is not. Who knows which electronic components reside inside a side mirror module? It has become standard to have a mirror heating as well as an automatic adjustment of the mirror position. In the future, the side mirror module will further combine a memory function for the mirror position linked to an individual driver, parking position stowing of the complete mirror housing, electro-chromatic controlled dimming in case of glaring, light for illumination of the entry area in darkness, the side turn indicators, temperature sensor as well as an antenna for keyless entry.

Microsystems Applications and their Interaction

In reflection of the last Advanced Microsystems for Automotive Applications conference (AMAA) held in April 2000, it can be stated that a significant number of microsystems have already found their way into automotive vehicle applications. It is expected that in the near future even more MST-based systems will be introduced and classic systems will be replaced by smart and reliable MST/MEMS solutions.
Examples of classic technologies being replaced by MST solutions include early MAP sensors realized in LVDT technology replaced by piezoresistive and capacitive MST devices, electro-mechanical "ball and tube" airbag switches replaced by capacitive and piezoresistive MST devices, and most recently, exhaust gas recirculation (EGR) pressure ceramic capacitive sensors being replaced by piezoresistive MST devices. Currently the majority of wheel speed sensors are of the variable reluctance variety. A number of suppliers are evaluating the use of hall effect and magnetoresistence ratio solutions to replace the classic approach.
While new sensor products (e.g. CMOS camera solutions, radar and infrared systems) also create new features, e.g. for safety systems, it becomes important to use the information currently available from existing systems. When one observes a media quality sensor (e.g. oil), it is obvious that measuring one parameter, e.g. viscosity, is not sufficient to assess true oil quality. In addition to

App.	Sensor/Structure	Status	MST Opptnty
Seat Control	Presence	Limited Prod.	Low
	Valve	Future	Low
	Displacement	Future	Low
Climate	Mass Air Flow	Future	Medium
	Temperature	Production	Medium
	Humidity	Future	Medium
	Air Quality	Future	Medium
Compressor	Pressure	Production	High
Control	Temperature	Production	Low
Security	Proximity	Limited Prod.	Low
	Motion	Limited Prod.	Medium
	Vibration	Limited Prod.	Medium
	Displacement	Limited Prod.	Low
	Keyless Entry	Limited Prod.	Medium
Windshield	Optical	Limited Prod.	Medium
Wipers	Optical	Future	Medium

Figure 1: Applications Of MEMS/MST - Comfort, Convenience, Security [1]

App.	Sensor/Structure	Status	MST Opptnty
Coolant System	Temperature	Production	Low
	Level	Limited Prod.	Low
Tire	Pressure	Limited Prod.	High
Engine Oil	Pressure	Production	High
	Level	Production	Low
	Contamination	Limited Prod.	Medium
Brake System	Pressure	Limited Prod.	High
	Level	Future	Low
Transmission	Pressure	Limited Prod.	High
Fluid	Level	Future	Low
Fuel System	Pressure	Limited Prod.	High
	Level	Future	Low
	Pressure (Vapor)	Limited Prod.	High
Vehicle Speed	Velocity	Production	Medium

Figure 2: Applications Of MEMS/MST -On Board Vehicle Diagnostics [1]

App.	Sensor/Structure	Status	MST Opptnty
Digital Engine Control			
Fuel	Level	Production	Low
Cylinder	Pressure	Future	Medium
Manifold -MAP	Pressure	Production	High
Barometric	Pressure	Production	High
Eng Knock	Vibration	Production	Medium
Mass Airflow	Flow	Limited Prod.	Medium
Exhaust	Gas Analysis	Production	Low
Crankshaft	Position	Major Prod.	Medium
Camshaft	Position	Limited Prod.	Medium
Throttle	Position	Limited Prod.	Medium
EGR	Pressure	Production	High
Fuel Pump	Pressure	Future	High
Torque	Torque	Limited Prod.	Medium
Continuously	Temperature	Future	Low
Variable	Pressure	Limited Prod.	High
Transmission	Microvalve	Future	Low
Fuel Injection	Pressure	Limited Prod.	High
	Nozzle	Limited Prod.	High
Diesel TurboBoost	Pressure	Limited Prod.	High

Figure 3: Applications Of MEMS/MST -Engine/Drive Train [1]

App.	Sensor/Structure	Status	MST Opptnty
Antilock	Steering Position	Production	Medium
Braking,	Wheel Rotation	Production	Medium
Vehicle	Pressure	Limited Prod.	Medium
Dynamics,	Acceleration	Limited Prod.	High
Suspension	Valve	Future	Low
	Acceleration	Limited Prod.	High
	Rate	Limited Prod.	High
	Displacement	Limited Prod.	Low
	Rollover	Limited Prod.	High
Airbag Actuation	Acceleration	Production	High
	Press.-Canister	Future	Medium
	Press.-side Impa.	Limited Prod.	Medium
Seat Occupancy,	Presence/Force	Limited Prod.	Medium
Passenger Position	Displacement	Limited Prod.	Medium
Seatbelt Tensioner	Acceleration	Limited Prod.	High
Object Avoidance	Presence/Displa.	Limited Prod.	Medium
Navigation	Yaw Rate/Gyro	Limited Prod.	High
	Wheel Rotation	Limited Prod.	Medium
Road Condition	Optical	Future	High

Figure 4: Applications Of MEMS/MST- Safety [1]

the evaluation of the actual measured parameter which will be used to infer a condition, a more complex analysis of the media itself (e.g. including conductivity, search for specific gravity) will lead to better results. This information again could be shared by several other applications and functions including engine/transmission control, definition of service cycles, or the sensing of aggregate problems.

Potential applications for so-called sensor fusion [the ability to share the information obtained from one sensor as inputs to a number of different and separate systems] approaches include active safety systems, advanced driver assistance systems, automatic suspension systems, as well as climate and heating control. Some of the above-mentioned applications are safety critical. It is crucial for them to assure accurate, reliable, and failsafe operation. However, reducing the required number of sensors translates into increasing the demands on the signal processing and communications functions in order to maintain acceptable system performance.

So far three communication networks are commonly used – chassis, body and infotainment. Reliability can be improved with new protocols as well as the use of synergies. Interesting developments include additional networks such as wireless, (which could be based on bluetooth for internal connections) and solutions using existing power lines (for more details refer to the article by Yamar). With falling prices on the interface side for optical transmitters, it is conceivable that not only the infotainment network but also the body and/or chassis network could be realised as fiberoptic systems. Inherent advantages of this approach would be lighter wiring, higher bandwidth, faster communication and fewer EMI/RFI problems. Taking these possibilities into account, it is difficult to decide for the appropriate sensor/actuator interface. But it remains clear that the ability for communication becomes essential for all microsystems of future cars.

A host of "energy hogs" – radio, rear window defroster, and up to 50 control motors for automatic windows and other convenience features – rely on the current 12 V automobile power network. When they all demand power, especially in adverse winter conditions and with insufficient battery charge, the capabilities of current electrical systems are exceeded. There is already an industry agreement that the right answer is a 42 V solution. It has been estimated that adoption of the 42 V electrical system and using it to its fullest could result in a 5-12 percent savings in fuel economy plus a lowering of exhaust emissions in the range of 10-15 percent depending on the configuration. A number of technologies, such as electric steering, electric brakes, fully active suspension systems, and the electromechanical actuation of engine valves, are being developed and will be added as infrastructure can support them. The feasibility of a number of other items, such as electric oil pumps, electric air conditioning compressors, and electric water pumps, are being discussed.

Furthermore, a number of X-by-wire systems will bring automatic closed-loop systems in the car. Right now these are normally open loop, meaning that the driver controls the functions and that the sensors record his actions.

Giving the total responsibility of vehicle control exclusively to these closed-loop control systems, would not appear to be judicious. There would be a need to have a manual override function. In addition, due to the safety critical nature of the specific application, (e.g. brake by wire, self-test diagnostics, steer by wire), it would be prudent to have self-test diagnostics, redundant sensors/actuators in addition to a "limp back" mode function available. The low cost associated with MST-bases solutions could provide a viable approach to these applications.

Automotive Market Figures

All cars on the road include an engine. But some of them have intelligent driver support systems, a multistage airbag or sophisticated entertainment features. These are selling features of modern cars. The 2000 worldwide production of automobiles was about 40 million units.

Electronics continue to constitute a larger and larger part of the total cost of a car. In 1980, electronics accounted for a mere 2 percent; in 1997 this grew to 10-15 percent, and in some cars today it has already reached almost 30 percent.

Ian Riches of Strategy Analytics sized up: "We see the world-wide demand for auto electronic systems reaching $90.7 billion in 2000. This is forecast to grow to $145.5 billion by 2007.

The average growth rate over the period 1999 to 2004 is expected to be 8.5 percent – helped by strong growth in developing markets (Automotive World, December 2000)." And to stay with the given example of in-car network solutions, gateway modules, which manage communications flow over Can buses, are becoming critical to automobiles as demand for in-car electronics increases. Motorola estimates that the gateway market will grow from 4 million units in 1999 to 14 million in 2003 (Global Design News, October 1999). Now a car comprises between 15 to 60 electronic control units and the number is expected to grow above 100 per vehicle over the next four years.
The world market for automobile high temperature electronics of 1998 was $78.3 million and is expected to grow to $204.8 million by 2003 and $561.3 million by 2008 (Source HITEN, The world market for High Temperature Electronic, 2000). Applications can be found in the engine compartment as well as the aftertreatment section, in the transmission, in new CO_2-based climate systems and upcoming brake control solutions.
Based on the recent injuries caused by tire problems, monitoring systems for tires are becoming of great interest. Further incentives can be expected due to the market entry of run-flat tire systems which need accurate sensing for loss of pressure to trigger driver awareness. In addition, systems for measurement of friction and forces are under discussion. This could lead to sophisticated stability control systems because of the direct observation of adhesion and prediction of itself. In 1999 the global tire market was worth around $68 billion at manufacturer selling prices. Globally this figure equates to 1.07 billion units, of which 541 million were aftermarket passenger tire sales (Automotive World, Dec. 2000).

Challenges for Automotive Engineers
According to Roland Rechtsteiner (project manager of Roland Berger & Partners), the next market-released vehicle innovation has a 9 in 10 chance of being influenced by electronics (Automotive Engineering International, October 2000). Beside customer requests, governmental regulations are forcing functions. Even for the near future, this will remain valid. Keywords like economy, environmental issues as well as safety aspects drive the automotive industry towards implementing sophisticated control loops (e.g. for improving economy and decreasing environmental hazards) as well as specific sensor systems (e.g. child seat detection).

The already mentioned 42 V system and much more the transition of the nowadays power architecture to the complete adoption of a 42-V mono voltage storage system is expected to need more than 10 years. According to a Standards&Poor's forecast, about 13 million vehicles with 42 V system will be produced by 2010. These cars might incorporate camless engines, electromagnetic valve actuation, steer and brake by wire, an alternator/starter system, electric water pump, electric air conditioning, and others. "One of the big benefits of 42 V is that there have been standards developed for it," points out Remy Kaiser, European director of Technology, Environment and Quality at Delphi Automotive Systems. "We don't have standards for the current voltages." (Global Design News, October 2000)

One of the interesting things happening is to see the migration of multimedia applications into vehicles. Given the power of state-of-the-art processors and the outstanding development of wireless networks as well as the Internet - being seen as an information media, a car will have sophisticated new functionalities. Some of them have already entered the market, including tele-aid, dynamic navigation systems, and Internet access on the road or electronic road pricing. Other systems, including vision enhancements or active noise control by car speakers, are still under development. None of these systems will be realised without microsystems. But given the number of additional information, the driver needs to deal with proper Human-Machine Interfaces (HMI). For vision and instruments, this could be an organic display printed on a standard surface.
But the future HMI will be a mixture of visual and verbal information exchange. The ultimate target for research and development, however, should be to apply speech technology wherever feasible and whenever it makes sense. For vision systems holographic applications might be realised.

Figure 6: HMI for multi-media application by CAA (Car PC)

Today different HMI solutions exist side by side. Most of the major controls (air conditioning, lights, seats, windscreen wipers, etc.) are designed by different departments of the OEM. HMIs of audio equipment, navigation systems and others are made by several suppliers who have the knowledge in Car-driver interaction, but different realisation philosophies. Phones, PDAs and other equipment are designed for use outside the vehicle, but will be part of

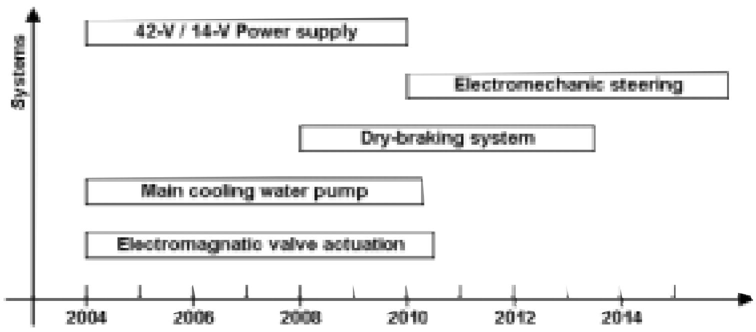

Figure 5: Market penetration of 42 V systems (Hella KG Hueck & Co., Automotive Engineering, October 2000

the information equipment of the car. Mr. Roessger of CAA AG points out that today we end up with a variety of HMI philosophies leading to confusion and driver distraction. An integrated system design is needed to create HMI solutions that are consistent, meaning all subfunctions follow the same driver-system interaction philosophy.

MST development has received a significant amount of R&D funding over the years. In applications where the media is benign, it is relatively simple and inexpensive to package an MST device. These packages take the form of classic semiconductor packages, e.g. dual-in-line. However, most automotive applications require MST devices to be subjected to harsh media (e.g. engine oil, gasoline, radiator fluid), severe EMI/RFI, extended temperature ranges and severe shock and vibration. As a result, a robust package is required. It is not unusual for an MST device to comprise less than 20 percent of the total cost of a completed sensor. The remaining 80 percent is attributed to packaging, testing, and signal conditioning electronics, packaging and testing being the primary cost components. Therefore, it behooves MST suppliers to look aggressively at low cost packaging and testing solutions in order to accelerate the adoption of MST devices into automotive

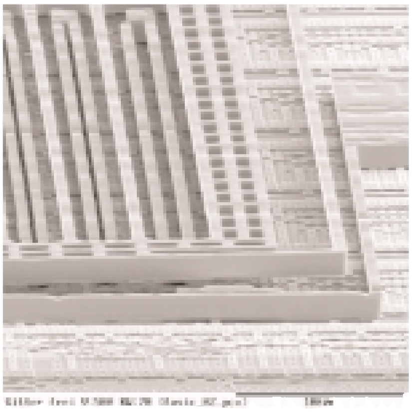

Figure 7 – Additive Integrationof an acceleration sensor on the CMOS substrate (IMSAS)

electronic systems. A novel approach to packaging is that of the "embedded sensor." Here, the sensor uses the package of its next level of integration subsystem to provide protection from the environment.

Examples of major developments of significant importance to microsystems are:

- Human-Machine-Interfaces
- Sensor and data fusion
- Multistage airbags for adaptive safety
- Collision avoidance systems
- Adaptive light distribution system
- X-By wire systems
- High temperature applications
- Modularisation (Plug and Play) as well as standardisation
- Entertainment and diagnosis func.
- Software functions on demand
- 32-bit signal processing

Mr. Balle of Renault stated that software would also be used to give different vehicle function parameters required by different regions. "Today we design the mechanical system to be able to function in the whole range of parameters, and the software regulates these parameters (Global Design News, Oct. 2000)."

Looking at the design process of a car, it is important to realise the different lifecycles for the needed modules. Today an automobile will be designed in five years, where control modules have a lifecycle of about three years. Because of new functions, as well as cost issues, the lifecycle for microsystems is within two and seven years. Design to software in six months is feasible. It is a big challenge to bring all these modules together and assure proper function. Furthermore, at the beginning of the design process it is impossible to predict the design of the microsystems or even the software implemented. That means standards and interfaces are becoming more and more important. For engineers, this translates into to the ability to deal with rapidly changing products and finding the right answer for their implementation.

Conclusion

The technologies already exist, but until now, there has not been such a pressure to deploy them at low cost in the automotive environment. With that in mind, the industry is moving ahead on several levels. The first is to deploy more advanced electronics/microsystems on the vehicle platform to improve safety systems, stability, visibility and telematics.

The point of replacing mechanical systems with microsystems results in systems that are more cost effective for the manufacturer, and are equivalent or better for the driver. Most mechanical systems are set up for an optimal operating point and then they work with that point regardless of the speed of the car or the driving conditions. The electronic as well as microsystems are much more adaptable, and function at the optimum level in a given driving situation. Sensing hundreds of parameters leads to a steadily growing information flow. Using the available information in an innovative fashion while approving data consistency and creating 100 percent reliability could be the biggest challenge of new car design.

Ultimately, the aim is to predict rather than measure.

Reference

[1]R.Grace, Automotive Applications of MEMS/MST, Sensors Expo Proceedings, Detroit MI, Sep. 19, 2000 (www.rgrace.com)

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