Scanning Advanced Automobile Technology

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ABSTRACT | This introductory article overviews the progress of electrical, electronics, software, and other relevant technologies that shape the modern automobile. Some of these technologies are described in more detail in the articles that comprise this special issue.

KEYWORDS | Automated highway systems; automobiles; automobile safety; intelligent transportation systems (ITS); intelligent vehicles; road vehicles; vehicle electronics; vehicle software vehicle communications

The automobile is an embodiment of delicately balanced form and intricately engineered function, designed to appeal to the innate emotions of consumers and their personal mobility needs and wants, while meeting the demands of society at large. For more than a hundred years automobiles have been in both a continuous state of refinement. This has been made possible by advancements in a wide spectrum of scientific and engineering disciplines and the associated evolution of enabling technologies, such as microprocessors and wireless networks.

Advances in electrical, electronics, computing, communications, controls and software technologies are the central keys to enable automobile evolution in a sustainable future.

World-wide, the number of automobiles in operation has shown relentless growth for more than a century (Fig. 1 shows data for the past 70 years). Along with this growth, societal demands for cleaner, more fuel efficient and safer vehicles and consumer demand for features associated with comfort and convenience have also increased.

During the more than one hundred year history, much has changed "beneath the hood" and within the vehicle cabin area. These changes have been enabled by advances in electrical, electronics and software technologies as shown in Fig. 2. A coarse history of the automobile reveals the broad and growing role played by these technologies in enabling vehicle-level features, examples of which are shown in the top part of the figure with arrows pointing to approximate dates when first applications appeared in the marketplace.

The rapid development of electronics and software tools during the last four decades coupled with the increase in computational speeds and

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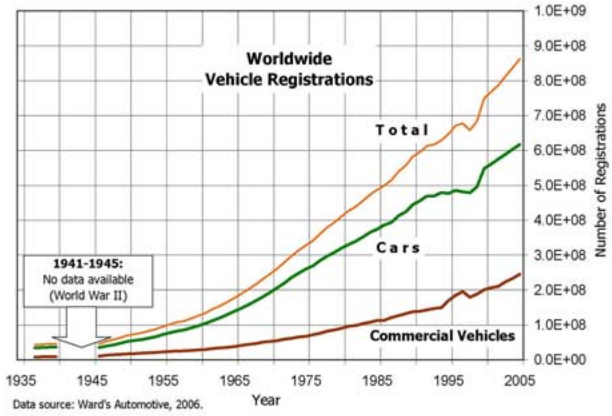

Fig. 1. ***On a worldwide basis, the number of automobiles in operation has grown relentlessly.***

a reduction in the cost of these tools, has touched every aspect of life, industry and, of course, the automobile. Automobile manufacturers have begun replacing bulky hydraulic or mechanical parts with electronic and mechatronics modules, communication networks, and associated software, recognizing the benefits of doing so. These benefits include improved reliability, better controls, lower weight, better fuel economy, lower emissions and improved safety.

The availability of computers on board the vehicle and advances in sensor technologies provide computational power and real time information, which can be used to implement advanced control algorithms to optimize subsystem performance and deliver a number of features that may have been considered impractical a few years ago. Examples include a number of adaptive control technologies. Adaptive cruise control, for instance, involves a range sensing technology to ensure that a driver-preset distance is maintained, with respect to the vehicle ahead. Adaptive headlamps involve an optoelectronics technology that steers the headlamps along the vehicle path, especially around curves, instead of just along a line-of-sight. Adaptive climate control is a zone and context-specific heat, ventilation and air-conditioning (HVAC) technology that adjusts interior "climate" based on the number and location of occupants and the state of the windows (closed or open). Adaptive sound technology adjusts sound levels based on the number and location of occupants and interior noise levels. These are some examples of new comfort and convenience related technologies that have become feasible in recent years. The broad message here is that technology is enabling the automobile to adapt to the physical and information environment of the roadway and, within the vehicle itself, and to the preferences of the driver and passengers. The convergence of controls, communications and the commoditization of networked embedded computing has begun to place computational intelligence in and around the automobile—in areas that may have been hard to imagine in the past.

Advances in electrical, electronics, communications, controls and software technologies are accelerating the implementation of sophisticated automobile controls and integrated communications. As shown in Fig. 3, it is not just intra-vehicle communications that is making rapid strides, but also inter-vehicle and vehicle-to-roadside communications. Given the progress of computing and communications technologies, other examples that could be envisioned include the "curbside" communicating with the vehicle—taking the current automatic road toll services to new forms involving "micro-credit" payments. This form of electronic payment could be applied to a number of journey related services such as gasoline purchase, parking, food and in-vehicle information and

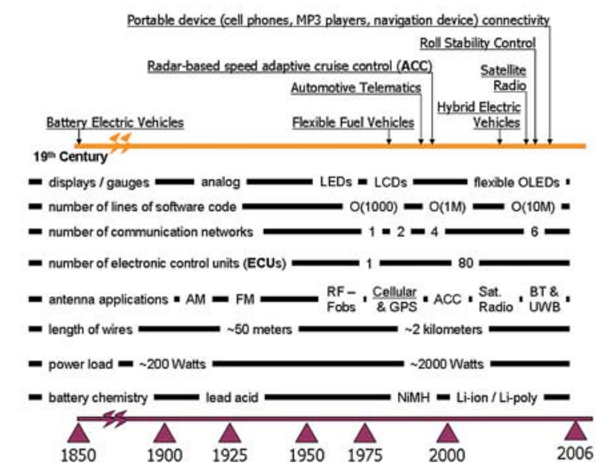

Fig. 2. ***The Progress of Electrical, Electronics & Software technologies (compiled from public industry publications).***

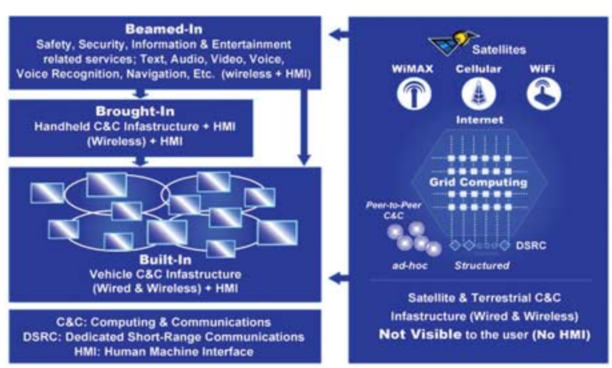

Fig. 3. ***Automobiles are well on their way to being composed of not just built-in modules but also brought-in devices, with associated services, and "beamed-in" services.***

entertainment. With vehicles acting as sensors of traffic conditions, road conditions, or weather conditions, to name some applications, the automobile may have a new role to play as an environmental probe.

Two scales may be used to view the automobile in the context of its operating environment. One is a large-scale "system-of-systems" view in which automobiles are components of a multimodal transportation system, a multimedia information system, an even larger planetary (fossil-fuel, bio-fuel or hydrogen) energy system, and an atmospheric chemistry system. At this scale, 900 million or so automobiles "roam" this planet (Fig. 1). In addition to being a component in a large-scale physical and chemical system, the automobile is becoming a component in a rich information infrastructure system (Fig. 3), opening a new frontier for electrical, electronic & software technology enabled services.

At the second scale (Fig. 4), the automobile may be viewed as a complete system, composed of powertrain, safety, chassis, body and information-entertainment (infotainment) sub-systems. Indeed, during the past thirty years there have been steady (incremental) advancements at both scales.

The public demand for "clean air" in the early 1970's signaled the urgency to improve energy efficiency and clean tailpipe emissions associated with transportation systems. This time period coincided with the development of the first commercial microprocessors, which were quickly applied to electronically control engines to improve fuel efficiency and reduce undesirable tailpipe emissions.

The microprocessor era, heralded by the electronic engine control module, next led to network communication modules that ushered multiplexed local area networks into automobiles. While multiplexed networks were introduced with a view to reduce wires, their ability to distribute functions involving controls, human machine interaction and data exchange has, in fact, has led to a growth in the complexity of wiring harnesses. Two measures of wiring complexity are the number of circuits and the number of wiring harness (connector) pins—both have increased greatly, (the number of circuits increasing from about 400 to just under 2000 and wiring harness pins growing from 150 to just 1200), mainly in the last ten years. The steady growth of consumer demand for features based on comfort and convenience and the increasing societal demand for improvement in the safety and sustainability (fuel economy, greenhouse gas emissions, reuse & recyclability) attributes of automobiles has resulted in a significant increase in electronic control units (ECUs). The number of ECUs has grown from just one or two per vehicle in the 1970's, to over 70 in today's high-end automobiles, which offer about 500 features. These ECUs span a range from 4 bit to 32 bit processors.

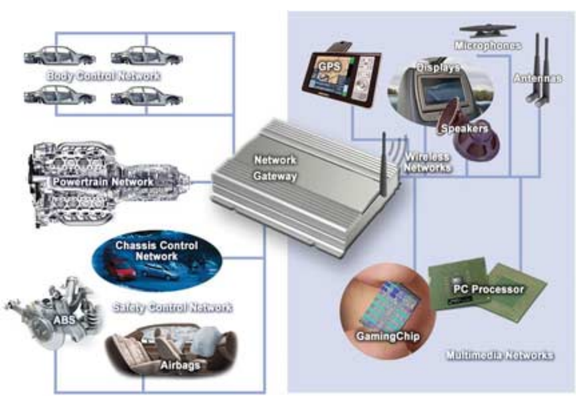

Fig. 4. ***In-vehicle communication networks.***

This complex computing and communications system, viewed from a total vehicle standpoint, poses some unique challenges in terms of electromagnetic compatibility, susceptibility and interference. The ECUs are high-speed digital bit stream processors and the interconnecting wire-harnesses are ready antennas. The vehicle is like a closed "Faraday cage" environment in which safety critical modules (air-bag deployment, for example) need to co-habit with infotainment modules and engine control modules—all less than a meter from spark plugs in the internal combustion engine. This makes the design of the electrical distribution system including the design of shielding, grounding points, packaging of wires into bundles (harnesses) and placement of radio receivers and antennas around the vehicle, a demanding, yet arguably under-appreciated task, as these are non-functional requirements, hidden from the end-user.

As we look ahead, the growth of electronics has set the stage for the steady "electrification" of the automobile—one in which core mechanical components such as engine valves, chassis suspension systems, steering columns, brake controls, and shifter controls are replaced by electromechanical, mechatronics, and associated safety critical communications and software technologies. These changes place increased (electrical) power demands on the automobile. What started as the need for a few hundred watts of power (for a light bulb or a starter) in the early part of the last century is today a demand for more than 2000 Watts of power (Fig. 2).

The automobile is clearly a principle component of any transportation energy equation. Battery technology, first used in battery electric vehicles during the 19th century, then mass manufactured in early 20th century for use in ignition systems, headlamps, windshield wipers, has made much progress with advancements in the science and engineering of batteries: their energy-density has been significantly improved through advancements in electrochemistry, new composite materials have improved packaging technology making them smaller, more amenable to reuse and recycling and virtually maintenance free.

Given the steady increase of electrical loads in automobiles, 42 volt batteries have been proposed by industry-university consortia. The limelight today is on batteries with alternative chemistries such as those based on NiMH (nickel metal hydride), Li-ion (Lithium ion) and (Lithium polymer). At a vehicle level, batteries are components in an electrical power management system whose objective is to manage power generation, storage, distribution, consumption and regeneration efficiently. Such systems include one or more batteries, an alternator, electrical power cables, and junction boxes with microprocessors to deliver power management features.

During the next few decades, electronic controllers, micro-electromechanical systems or MEMS, and nanoscale electro-chemical sensors and actuators will play an important role in emissions treatment—enabling the electro-chemical systems needed to drive down the percentage of hydrocarbons, oxides of carbon & nitrogen from tailpipe emissions. Today these electronic controllers, sensors, and actuators are used in the multistage treatment of exhaust gases as they travel from the internal combustion engine to the tailpipe to ensure that hydrocarbons and oxides of nitrogen are trapped and reduced to clean tailpipe emissions.

With the cost and package-size reduction of microelectronics, microware electronics, photonics and ultrasonic sensors, these technologies have become viable components of automobile convenience, safety and security systems. Advancements in electronics, communications and control technologies are enabling a number of new features such as "360 degree vision," adaptive cruise control (ACC) and "automatic park assist," which maneuvers a vehicle into a parallel parking spot by measuring the space around a vehicle and planning a smooth path.

Passenger safety, in terms of driver and passenger airbags, has evolved into airbag systems including inflatable side curtains, inflatable seat belts and airbags for rear seat passengers. Going one step beyond occupant safety, today's technologies have begun to deliver pedestrian safety technologies—interior warnings that signal the presence of a pedestrian in the collision path, airbags that inflate externally when a pedestrian is struck, are two examples. Safety has evolved into an integrated (powertrain, chassis, body, vehicle and external information system) solution, often referred to as active safety: The anti-lock braking system (ABS) is one of the first examples of dynamic or active safety. Today's mass produced entry level vehicle offers an advanced form of active safety called traction-control. As shown in Fig. 5, an interactive vehicle dynamics system, using traction control technology and ABS, delivers greater stability in poor road conditions. The red car (lower vehicle in the picture) does not have this technology and is seen losing control while negotiating a curve.

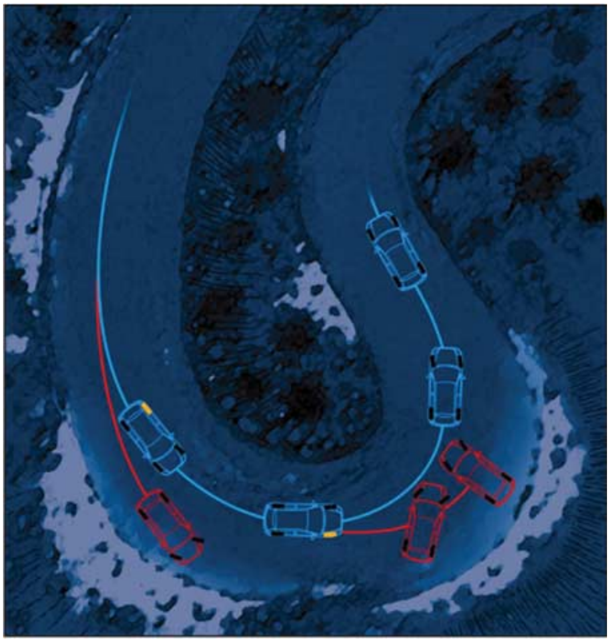

Fig. 5. ***Traction control technology keeps the blue vehicle (the upper one in the image) on track.***

Currently, there are several public-private partnerships in place across the world to experiment with vehicle-to-vehicle (V2V) communications and vehicle to roadside infrastructure integration (VII). These efforts are aimed at demonstrating the concepts of a new class of road related services (such those related to traffic management and mobile electronic payments) for both safety and convenience applications, as envisioned in Fig. 6. The IEEE 1609.x & IEEE 802.11p wireless communication standards are being proposed to provide short to medium range communications service in support of public safety and private operations in vehicle communication environments. For instance, the IEEE 802.11p is expected to be the basis for Dedicated Short Range Communications (DSRC), to establish communication between vehicles and from a vehicle to a network of roadside units.

Besides exterior and interior design, the single biggest differentiation that an automobile can offer, arguably, is a "living room" comfort-on-wheels environment. Infotainment, the end-user experience of having a combination of information and multimedia entertainment services and associated devices integrated into the automobile, is the industry's response to such a need. Examples of information services include real-time road traffic information or cellular communications (for voice and data) using vehicle integrated human-machine interfaces such as buttons, knobs, displays, loudspeakers and microphones. Multimedia entertainment services and devices include those provided by traditional terrestrial (AM/FM) radio, satellite radio, CD and DVD, portable MP3 (music), video player and game systems.

Fig. 6. ***Vehicle and (roadside communications) Infrastructure Integration or VII—an emerging public-private effort, in the United States, based on the IEEE 1609.x & IEEE 802.11p standards.***

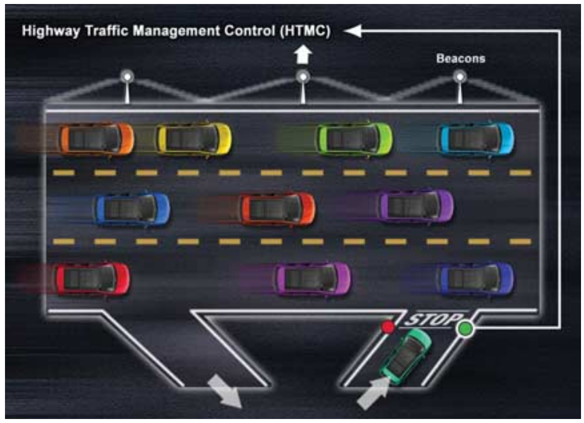

Fig. 7. ***Integrated Highway/Vehicle System.***

As the vehicle is viewed as a component in the broader system-of-systems, another important aspect to consider is that of traffic congestion management. With respect to traffic flow, today's automobiles are treated as passive users. Highway traffic is an open loop dynamic system, with minimal local control at ramps, having limited measurements for further improvements. Just as safety, fuel-economy and emissions are the essential attributes of the automobile as seen by society, traffic congestion management is increasingly being recognized as an essential attribute of the system-of-systems in which the automobile is a component. Severe congestion may force consumers to look for alternative modes of transportation and cause local government to levy taxes—a case in point being London's congestion fee or Singapore's vehicle tax.

With the development of V2V and VII technologies, the road infrastructure could be upgraded to take advantage of these vehicles for the purpose of effective management of traffic. For example, vehicle to roadside (infrastructure) communication, currently being used for automatic toll collection, could be used to collect vehicle speed, location, points of origin and destination, at frequent intervals in time. These technologies could lead to the traffic highway system shown in Fig. 7 where the vehicle is no longer a passive user of the highway system, but instead acts as a sensor and actuator in this high level traffic management system.

In Fig. 7 the highway traffic management control (HTMC) system collects data in real time, calculates current traffic status, estimates future demand, and processes the data to extract the information required by the roadway controller which, in turn, generates commands for ramp metering, speed limit distribution at various sections of the highway as well as generates routing instructions for vehicles. The speed limits and routing instructions could be communicated directly to each vehicle in a more advanced system or via variable message sign boards along the highway. The HTMC system can be designed to be flexible to operate at various levels of current and future technology. The feedback structure of the HTMC system is shown in Fig. 8.

The measured outputs of the traffic system could be flow rates, queue-length at ramps, position, speed, origin and destination of individual vehicles, road conditions, accident data depending on the system under consideration, whereas the control inputs are ramp metering, speed limits and possibly routing instructions. The outputs are sampled in space and time at sampling periods T_0 (where T_0 could be a vector) and collected by the data acquisition and processing (DAP) system. Depending on the system under consideration, this could be a massive flow of data which would need to be processed on line and in time fast enough to be of use to the feedback control system. The

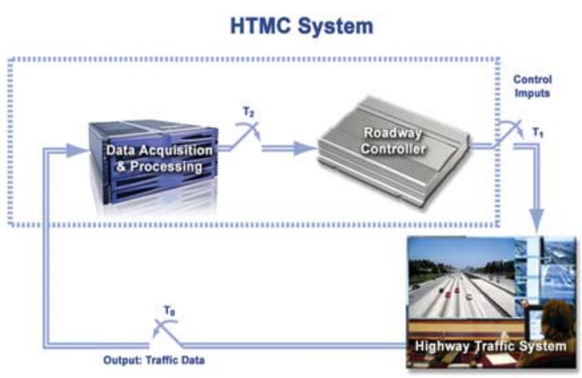

Fig. 8. ***Structure of HTMC system.***

DAP system outputs certain aggregated measurements to be used by the roadway controller.

Such a system will make the use of inaccurate and high-maintenance inductor loops redundant and open the way for more efficient management of congestion and roadway incidents. Ramp metering could be optimized and further improved with more accurate and frequent traffic flow measurements. An additional element of traffic management is incident detection, which has been a topic of research for many years without the development of effective systems to detect and identify incidents. This is because the vehicle has been a "move-alone" entity, isolated from the roadside information infrastructure much like a computer might have been a stand-alone entity two decades ago. V2V and VII developments will simplify incident detection and increase the efficiency of traffic management. For example, on-board diagnostics could identify the cause of the disturbance and classify it as an emergency or a "breakdown" and communicate specific needs to the roadway infrastructure. If it is an accident, its severity, including the number of people involved and condition of the vehicle, could be communicated to the emergency or roadside assistance infrastructure. This will allow dispatch of the appropriate form of assistance—an ambulance of the right capacity or a tow truck with appropriate towing capacity and capability. Closing the loop between the vehicle and infrastructure as shown in Fig. 8 would be a significant step forward in the evolutionary path of vehicle technology deployment as part of optimizing the greater multimodal transportation system.

The evolutionary deployment of vehicle technologies is an approach that is favored by automobile manufacturers due to the liability issues involved; costs, marketing and profitability considerations. Automobile driver's come from a wide range of the population with respect to age, experience, skills, physical and mental conditions of short-term (sleep deprivation, for example) and long-term nature—with different reaction times and different abilities and interests associated with how the various vehicle systems operate. The human-in-the-loop raises a lot of safety considerations for any technology to be deployed and often leads to a system that is slower and more sluggish than it needs to be. As the vehicle gets smarter, more sophisticated human machine interfaces such as touch screen displays that offer controls to not just the vehicle sub-systems but also to portable consumer phones, music players and handheld navigation units and game systems, are likely to evolve.

Looking into the future, full vehicle automation, an approach advocated by a number of researchers and the resulting notion of automated highway systems (AHS), could open the way for better traffic management tools with the potential of increasing highway capacity, reducing congestion and travel times. By taking the human out of the loop, vehicles aligned in platoons with short inter-vehicle spacing that travel at high speeds could dramatically increase highway capacity. The concept of AHS has been researched extensively in recent years. The United States Department of Transportation set up a national AHS consortium which led to a demonstration of full vehicle automation on an actual highway in 1997. This demonstration was viewed by the optimists as a success but by the skeptics as a science fiction system not ready for further consideration due to liability, human factors (especially during transitions in and out of platoons), and the lack of technological maturity, especially in sensing. The end of the AHS program for passenger vehicles gave rise to the Intelligent Vehicle Initiative where safety was the main consideration. The AHS program continued with automated trucks, in the early 2000s, where more uniformly trained drivers could function better during transitions and the large capital cost of trucks could justify the cost of expensive equipment required for automation. Fully automated trucks can be found in controlled environments where humans are not involved and safety is taken care off. Such environments include container terminals such as at the Port of Rotterdam in the Netherlands. Fully automated trains can be found in some airport terminals and theme parks. The United States Defense Advanced Research Projects Agency (DARPA) has supported two competitions of fully automated vehicles racing from San Bernardino (in the Los Angeles area) to Las Vegas through a desert dirt road in less than 10 hours. The first race (in 2004) did not have a winner while in the second (in 2005) several vehicles completed the race. DARPA's third competition has been extended to urban roads where automated vehicles will have to deal with a dynamic traffic environment. This event has been scheduled to take place in the fall of 2007.

In conclusion, the technologies that enable the design, engineering, manufacturing, distribution, life cycle management (including maintenance) and new-feature upgrades, of the automobile span a wide gamut. What started as a primarily steel-based product with horsepower as a dominant measure of performance, has evolved into a silicon and software driven system-of-systems with growing distributed intelligence that includes on-board, off-board and nomadic elements (as in smart phones, portable digital storage devices and portable navigation devices, to name some). As we scanned the technology gamut, it was clear that advances in electrical, electronics, computing, communications, controls and software technologies are the central enablers to drive the vision for ideal automobiles in a sustainable future—a future that will soon have over a billion automobiles in operation worldwide. ■