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Editorial
Embedded Systems for Intelligent Vehicles

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There is a growing need for some kind of personal driving assistant which is likely to become more acute as the free, independent, and very mobile baby boomers continue to age. Up to 86.5% of the US workforce commutes to work every day through personally owned automobile, often driving alone a car, a van, or a truck, at times in a commute as long as two hours. Urban planning and life style are among the factors, not likely to change in the near future, that make one choose private automobiles over public transportation. Recent developments in Europe have triggered significant increase in car-ownership rates in most of the 27 states of the current enlarged Union from 1995 to 2001—a trend that continues. In short, the man hours spent behind the steering-wheel are continually increasing worldwide, accounting for a lost productivity and increased safety hazards. At the same time, the activities that a driver could do from an isolated automobile have increased, for example, cell phones, televisions, listening to books, mobile computing, among others. If personal assistants can help alleviate some of the driving tasks, it could partially relieve the driver from the required intense attention to the road conditions. It can also help the steadily aging members of the population for whom a personal automobile is the only means of transportation. Intelligent personal driving assistants will improve safety, productivity, and the quality of commute.

Intense research in intelligent transportation systems, over the past 20 years, has produced a wealth of insights into the design challenges and applications of intelligent vehicles. A broad spectrum of published literature in this focus cover smart control, communications, and sensor systems residing on-board a vehicle rather than being centralized in traffic management headquarters or being included in road infrastructures. While infrastructural solutions have remained almost exclusively within the reach of governmental investors, the end-user benefits offered by intelligent vehicles technology are poised to attract private capitals from the vehicle manufacturing industry and eventually hit the consumer market. There is a rich set of opportunities for acquisition, trading, and management of location and time tagged information to support the next generation of intelligent vehicles. Intelligent vehicles advocate for autonomous capabilities, self-regulatory, and self-repairing systems to improve safety, driver comfort, and efficient use of infrastructures. Geographical-position-systems- (GPS-) based navigation, computer vision, radar and laser range sensors, adaptive control, and networking, among the others target problems like traffic flow control, smart communications, pedestrian protection, lane departure monitoring, smart parking facilities, and advanced driver assistance systems (ADAS).

We would require exceptional standards of reliability, quickness of response, and fault-tolerance from these systems, before we accept to delegate part of the intelligence required in driving and navigating on the road. Embedded systems are conceived to meet these standards, and as such they are a necessary step to implement advanced technologies onto a multitude of private vehicles. Ability to stay alert, aware, and to comprehensively factor in related information is required to navigate safely. Latest developments in sensors, distributed information processing, location aware information management, as well as context driven cognitive intelligence all indicate that intelligent vehicles will soon share the public roads with humans within the next twenty years. Embedded systems can carry artificial intelligence for vehicles to be "situated," that is, to specialize itself on the environment and habits of the driver and his or her family. Machine learning techniques based on statistical analyses of operating conditions can enable the device to predict changes in road conditions and consequently adapt to reduce the frequency of critical faults.

Embedded systems are also the natural host for solutions based on distributed intelligence, as opposed to centralized intelligence managed from a headquarters station.

Distributed intelligence can reach locations that centralized services may not be able to reach, for lack of infrastructures, or other structural limits. For example, in alternative to broadcasted wireless networks, smart communication devices can be embedded on vehicles and create a network that "runs on the road," exchanging messages when crossing other vehicles and continuously updating the traffic situation. The most positive scenario would see "intelligent" technology spread independently from governmental intervention through the channels of consumer market, probably in the form of embedded systems. This capillarity would foster a more distributed sharing of responsibilities and costs for introducing new advances of strong social impact. The diffusion of GPS personal navigation systems provides a good example of this scenario: GPS receivers deliver information on traffic jams and can partly redirect the circulation on less-used roads, however, when one buys a personal navigation system is rarely steered by the common good.

In launching this special issue, we aimed to attract discussion and up-to-date results on embedding intelligent systems onto vehicles, spanning applications in localization-based services, ad hoc networking and communication, smart sensors and sensor fusion, embedded vehicle controls, and embedded security. All these are bricks towards building an "autonomous" vehicle, where autonomous refers to the next generation of "automatic" devices. An autonomous vehicle is not necessarily unmanned. Instead, it should be intended as being able to react in a closed loop with the environment it operates in, adapting its behavior to provide improved services and safety to the human driver and other participants of the road environment.

In this context, we have brought together an issue filled with eight exciting articles that represent outstanding developments in this area. These were chosen from a bigger pool through the traditional peer review process. We thank both the authors and the reviewers in making this possible. The papers cover a broad spectrum of research results in: localization, information management, embedded image processing, navigation, context driven reasoning, and so forth as briefly outlined below.

In this issue

The articles presented in this issue cover a broad set of challenges being addressed by the research community in intelligent transportation systems. These have been grouped into four avenues: (1) location-based information and services: acquisition of vehicle location, management and delivery of these data to vehicles in transit; (2) radar-based service for distance and data exchange; (3) embedded image processings: methodology, omnidirectional imaging and stereo; And (4) security.

GPS/low cost IMU/on-board vehicle sensors integrated land vehicle positioning system

Robust, reliable, and swift access to current location of the vehicle is of importance to the autonomous and remote operation of vehicles. A less-obvious use of this data is to control the braking mechanism such antilock brake systems, detection, and avoidance of collision due to uncooperative vehicles sharing the road with oneself. Ability to make use of precisely measured terrain data, including such information as debries, pot-holes, and so forth will be limited to accuracy with which the vehicle can ascertain its self-position. Latest developments in sensor technology offer a variety of compact inertial measurement units (IMU) based on micro-electro-mechanical systems (MEMS) to acquire reliable information about the vehicles dynamics. Sensor fusion techniques offer a way of integrating such sensor data with that of global position sensors (GPS) extending the dependability of GPS in urban areas where they are known to be unreliable.

The article by J.Gao et al. presents a robust and reliable on-board vehicle sensor fusion based on low cost GPS and IMUS. They demonstrate an increased effectiveness as high as 92.6% in open-sky terrains and 65% in suburban areas based on real-time tests.

Real-time implementation of a GIS-based localization system for intelligent vehicles

In addressing the absolute localization problem by multisensor fusion, one step further is to consider the integration of the advantages brought by local maps from a geographical information system (GIS). Local maps can bear information on landmarks in the local area, for example, particularly visible traffic signs, or outstanding buildings and monuments. Extra exteroceptive sensors like video cameras or laser scanners can be used to locate these landmarks and aid GPS and IMUS with this additional information, thus increasing the precision of vehicles localization capabilities and compensating the defaults of the other sensors. Managing a GIS efficiently is a nonnegotiable prerequisite to this technology. The article by P. Bonnifait et al. describes GPS-IMU Kalman-based fusion and focuses on the problem of retrieving identification numbers (ID) of local maps from a geographical information system (GIS) at a frequency higher than the current commercial standard of 1 Hz. They use an enhanced map representation for efficient road selection and tackle cache memory management.

Broadcasted location-aware data cache for vehicular application

Ability to relate current location of the vehicle does not stop at obstacle detection and collision avoidance. Strategic and pragmatic information such as the weather and traffic conditions several miles ahead on journey, the location of a nearest restaurant, pharmacy, auto-repair shop and hospitals, for example, prove to be valuable at times. Other strategic information includes what is the traffic condition in one or more alternate paths between a nearest exit on our current journey and another several miles ahead. Contrary to the common belief, this information can be acquired—both static and dynamic—and delivered to through a set of well coordinated information services. The vehicles have an opportunity to act as the sensors and trade information, in addition to being able to buy information. Volume of data to be acquired, integrated, and delivered on demand would require new and efficient paradigms to manage the data in a distributed fashion. The usage value, and average transit time in a locale, and the density of traffic, and so forth determine the geographic extent to which a location tagged data will be proactively cached for a potential on-demand usage at a nearby location. The article by K. Sato and Fukuda outlines a set of metrics such as "scope" and "mobility specification" and model the performance of such a system to study the latency and quality of service obtainable through currently available digital communication infrastructures such as the cell phones.

This paradigm has a significant potential to be embraced by the commercial sector.

Embedded localization and communication system designed for intelligent guided transports

Interest in intelligent vehicle technologies is not limited to the private sector. Also public transportation is looking to enhanced communication and sensors to improve the safety standards. Indeed, trains allow for a higher space capacity and load carrying, thus posing less restriction on experimenting embedded intelligent systems. The metropolitan lines, with their high traffic and many train crossings, provide a challenging scenario for smart communications that somehow replicates the conditions of a road environment but with more controllable parameters. Smart communications can be used to gauge the distance from incoming vehicles, as well as to provide a channel for exchanging data on route conditions in the lines recently visited. Y. Elhillali et al. describe a radar-based multiaccess communication system and provide experimental data coming from a prototype tested on a train.

System platforms-based SystemC TLM design of image processing chains for embedded applications

Video cameras are becoming ubiquitous. In particular, cameras based on CMOS technology have steadily improved over the past decade to offer impressive overall performance over their CCD counterparts in terms of frame-rate and embedded image processing. To be efficiently embedded on intelligent vehicles, vision-based sensing follow the practice of coordinated hardware-software codesign widely consolidated for component design in the automotive industry. For researchers and developers in computer vision, this coordinated design was a more common practice in the early days of image processing, when the massive amounts of image data prompted researchers worldwide to develop ad hoc, parallel hardware to attain quasi-real-time computation. The advent of more powerful personal computers changed the situation, bringing researchers towards more software-oriented solutions. However, embedding vision on real-working vehicle systems necessarily passes through an optimization step involving hardware design. M. D. Cheema et al. outline a methodology for hardware/software codesign of image processing systems and guide the reader step by step through a complete case study, detailing all modeling tools and options they have selected.

Lane tracking with omnidirectional cameras: algorithms and evaluation

In the range of possible camera configurations, catadioptric omnidirectional cameras make an attractive choice for intelligent vehicle applications. A convex mirror projects an all-around view onto the sensor, so that a single camera mounted just behind the windscreen provides a view of both the road environment and the occupants inside the vehicle. One of such cameras provides information simultaneously for vision applications tackling road navigation—lane keeping, obstacle detection, and so forth—and for monitoring driver's activities to deliver services and driver assistance—sleepy drive detection, and so forth. The sensor does not need to be mechanically moved so that no resource conflict arises between different algorithms, and also such a solution minimizes the space occupancy inside the vehicle. However, a catadioptric solution with a convex mirror induces a decrease of resolution, and this factor may spoil the performance of some algorithms well tested for traditional cameras.

S. Y. Cheng and M. Trivedi describe some recent results concerning lane keeping with an omnidirectional color camera. The authors have adapted their own work on lane tracking developed for a traditional pinhole camera model to the omni-directional device, and investigate how the reduced resolution impacts on the performance.

StereoBox: a robust and efficient solution for automotive short-range obstacle detection

Video imagery plays an obvious and critical role in navigating a vehicle. Ready access to mask level design customization of cameras suitable for foveated algorithms and increased availability of high-frame rate video cameras have triggered a resurge in a variety of geometrically designed vision algorithms. Although the LIDAR sensors have proven to be effective in unmanned vehicles in off-road navigating vehicles, they are not suitable for sensing in the presence of human driven vehicles. Moreover, vision is more than sensing the 3D geometry of the scene ahead. It provides rich set cues based on texture and shade information effortless perceived by humans. So we are naturally interested in robust and efficient sensing of obstacles within a short distance from the vehicle based on visual data. Also, it is desirable to deliver the result in a form so as to facilitate integration of LIDAR and other data when available. The article by A. Broggi et al. presents a comprehensive and well-tested recent result on robust and efficient short-range obstacle detection.

State of the art: embedding security in vehicles

Similar to what happened to work stations and personal computers when they gained worldwide connectivity thanks to the Internet, we should expect that future networked vehicles become a target for malicious attacks with the goal of theft or, worse, remote control. Without going that far, today cars already rely on IT security for some applications such as immobilizers or digital tachographs which can be targeted by IT attacks. IT security systems for intelligent vehicles will take advantage of the knowledge gained in Internet security issues, but of course the scenario is completely different, and the characterization of possible attackers, their motivations, and their means requires a farseeing analysis of automotive-related problems. In the future, security issues will have to be tackled from an early stage of component design, and so the conscience of common attacks and state-of-the-art defenses becomes a significant expertise for anybody working in the sector. In their article, M. Wolf et al. provide an overview on embedding security in vehicles, with an eye to future scenarios and yet-to-come technology.

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