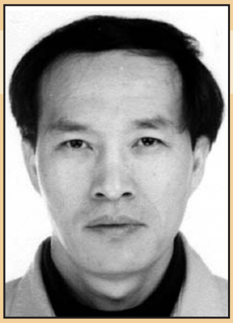

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IVS 05: New Developments and Research Trends for Intelligent Vehicles

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Eight years ago, the US Department of Transportation launched the Intelligent Vehicle Initiative, focusing on preventing highway crashes by helping drivers avoid hazardous mistakes. This was a significant new direction for USDOT safety programs, which had previously focused on crash mitigation—that is, alleviating the severity of crash-related injuries to people and property. Europe has also paid more attention to road safety in recent years; the European Road Safety Action Program aims to reduce road fatalities by 50 percent by 2010 (see http://europa.eu.int/comm/transport/roadsafety/charter_en.htm). Further evidence that driving safety and driver assistance have become worldwide themes appeared in the state-of-art research projects presented in June at the 2005 IEEE International Intelligent Vehicles Symposium.

The reason behind this shift in focus is simple. According to the USDOT IVI program, in the US alone, more than 42,000 Americans die each year as a result of 6.8 million accidents (www.itsdocs.fhwa.dot.gov//JPODOCS/REPTS_TE//13821.html). Even farther reaching is the impact of highway injuries—3 million Americans were injured in 2001. Survivors often sustain multiple injuries and require long hospitalizations. The cost to society is more than US $230 billion a year—representing a greater share of the nation's health care costs than any other cause of illness or injury.[1] The situation is even worse in developing countries. In 2003, more than 104,372 Chinese died as a result of traffic accidents—on average, 286 people die each day.[2,3]

Editor's Perspective

The IEEE International Intelligent Vehicles Symposium and the IEEE International Intelligent Transportation Systems Conference are the two major annual meetings sponsored and organized by the IEEE Intelligent Transportation Systems Society. This issue summarizes the major developments and projects reported on at IVS 05, and the next issue will focus on ITSC 05, which will be held from 13 to 16 Sept. at Vienna, Austria.

—Fei-Yui Wang

Here we discuss several selected topics from IVS 05 to provide a broad overview of intelligent-vehicle research perspectives and innovative projects. Specifically, we focus on advances in vehicle sensing, vehicle motion control and communications, and driver assistance and monitoring.

Intelligent-vehicle sensing

Two kinds of intelligent-vehicle sensing discussed at IVS 05 were *out-vehicle environment* and *vehicle state.* (In-vehicle environment is a third type, but since it primarily relates to a driver's state, we discuss related research in a later section.)

Out-vehicle environment sensing involves collecting information about the driving environment. Hot topics at ISV 05 included

- extracting lane boundaries, especially when not clearly marked or in bad weather conditions;
- detecting nearby vehicles and estimating their position, speed, and acceleration;
- recognizing the relevant traffic signs and traffic lights; and
- detecting the unexpected traffic participants (such as pedestrians) and obstacles.

Vehicle-state sensing focuses on measuring a vehicle's movement and monitoring its actuators. For example, researchers have studied how to detect

- a vehicle's position, velocity, and acceleration;
- an engine's pressure and temperature; and
- a tire's pressure, temperature, and friction coefficients.

Novel proposals presented at IVS 05 included out-vehi-

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cle sensing for bad weather and the integration of lane detection, vehicle localization, and vehicle-departure monitoring.

Out-vehicle environment sensing under adverse weather

CMOS/CCD cameras, FMCW (Frequency Modulated Continuous Wave) radar, and LiDARs (light-detection and ranging devices) are the three most frequently used surround sensors for out-vehicle environment sensing. However, conventional vision-based pedestrian detection is a difficult task, because pedestrians usually wear clothes in different styles and colors and might also carry items such as hats or bags of varied shapes. Moreover, illumination conditions and moving cars and bicycles also introduce distortions into the detection process.

To conquer such problems, researchers have applied thermopile and infrared sensors to intelligent vehicle systems. For example, Dirk Linzmeir and his colleagues have applied a thermopile sensor to measure an object's presence in the sensor's field of view, because objects of interest normally have higher temperatures than the environment.[4]

Using the same detection theory, Massimo Bertozzi, Alberto Broggi, and A. Lasagni have employed an infrared camera for pedestrian detection.[5] The camera can obtain 2D thermal images (see figure 1), from which users can analyze more morphological and thermal characteristics.[5] Using infrared cameras produced a much higher detection rate than that of conventional vision-based methods.

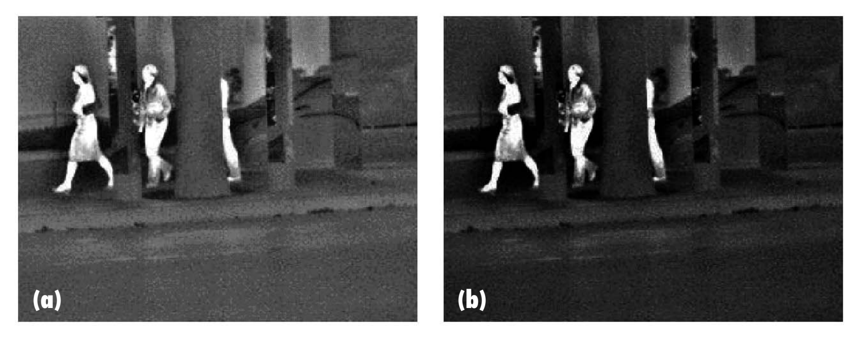

Figure 1. Preprocessing phase for a stereo infrared camera system: (a) the original input image and (b) the focus of attention.[5]

William Herrington, Berthold Horn, and Ichiro Maski further studied using image fusion techniques to combine the relevant information from both visible and infrared images.[6] The need for high frame rates in an automotive application motivates their investigation into computationally simple fusion. As figure 2 shows, they applied a computationally simple image-fusion technique, based on the Discrete Haar Wavelet Transform, to combine three images from cameras operating in different wavelength bands.

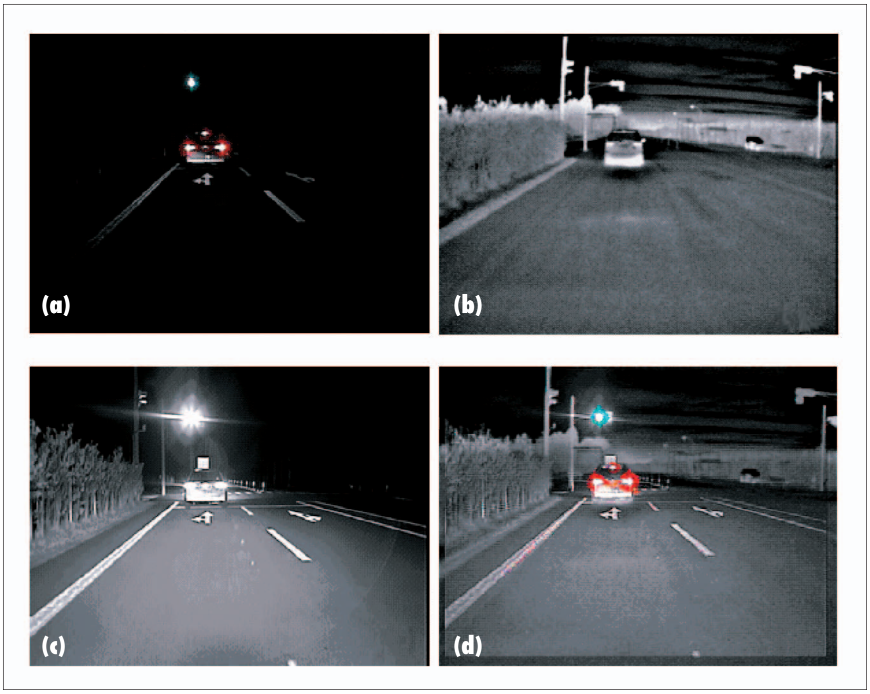

Figure 2. Applying a computationally simple image fusion technique based on the Discrete Haar Wavelet Transform to combine three images from cameras operating in different wavelength bands: (a) the color visible image, (b) the long-wave infrared image (7–14 μm), (c) the monochrome visible and near infrared (up to 1,100 nm) image, and (d) the two-level wavelet fusion result.[6]

Another advantage of thermopile and infrared sensors is their ability to detect pedestrians passively without illuminating the environment—the sensors don't electronically pollute the surroundings and are environment friendly. The only shortcoming is the cost, so realizing reliable yet low-cost on-vehicle thermopile or infrared sensors should be an interesting challenge over the next 10 years.

Conventional vision-based pedestrian-detection methods have also improved over the past two decades. Researchers recently presented several algorithms that can handle poor illumination conditions, such as rain or darkness. For example, Hiroyuki Kurihata, T. Takahashi, and I. Ide proposed an interesting weather-recognition method that uses a subspace method to judge rainy weather by detecting raindrops on the windshield.[7] They define the concept of "eigendrops" to represent the principal components extracted from raindrop images in the learning stage. Then, they use template matching to detect raindrops. In addition to identifying rainy or fair weather, this method could also help control windshield wipers.

Integrating lane detection, vehicle localization, and vehicle departure monitoring

Lane detection and vehicle position measuring are two basic intelligent-vehicle functions, and researchers introduced a variety

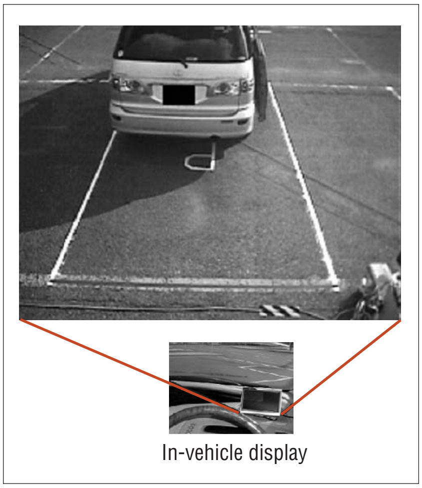

Figure 3. A parking assistance system using a single-camera infrastructure.[10] The top image shows the camera's view, and the bottom image shows the driver's view, including the small screen installed beside the steering wheel.

of related techniques at IVS 05. William Travis, Adam Simmons, and David Bevly discussed using LiDAR to measure the lane and vehicle's heading angle in an indoor scenario.[8] However, LiDAR exhibits less measurement accuracy than Inertial Navigation Systems, so the authors combined the two sensor systems for better results.

Localization is also an important functionality for navigating intelligent vehicles. However, the data obtained from GPS and cameras is sometimes uncertain and or even momentarily unavailable (in urban areas, for example). Frederic Chausse, J. Laneunt, and R. Chapuis studied the problem of GPS and vision-sensor-based localization, which combined GPS absolute localization data with data computed by a vision system to provide accurate vehicle position and orientation measurements.[9] They transform the position and orientation data into a global reference using a map of the environment and then estimate localization parameters using a particle filter. This lets them manage multimodal estimations, because the vehicle can be in the left or right lane. The best precision can supposedly reach 48 cm along the road axis and 8 cm along the axis normal to the road.

Vehicle motion control and communications

Developments in wireless and mobile communication technologies are advancing methods for exchanging driving information between vehicles and roadside infrastructures to improve driving safety and efficiency. The concept of multiple-vehicle cooperative driving has also recently emerged as a promising solution to traffic congestion.

Motion control

Drivers often can't see what's beside or behind their vehicle, especially when backing up. When parking, for example, the driver might have difficulty determining how close the car is to the curb. Furthermore, most vehicles don't have rear- and side-view sensors because they're too expensive and technologically challenging. To solve this problem, Yasuhiro Suzuki, T. Fujii, and M. Tanimoto have built an interesting multicamera system in a parking garage.[10] The system can easily identify a vehicle's position and send the information to the driver in real time (see figure 3).

Other novel parking guidance and monitor projects aim to collect, record, and share all the information in the garage, including the vehicle's license plate, available parking bay number, and toll collection.

Intersection collisions represent a significant portion of highway accidents, so roadside communications to assist drivers has also recently gained much attention. A potential solution is to supply drivers with timely alerts of imminent collisions. Chingyao Chan and Bénédicte Bougler set up an experimental radar, configured to observe a vehicle's left-turn motions with a trajectory (depicted by the yellow turning curve in figure 4).[11] The subject vehicle in the figure is initially traveling north and then turning west. As the figure shows, a left-turn pocket exists for the subject vehicles. The triangle in the figure represents the coverage area of a radar device used for monitoring the movements of other vehicles in the opposite direction. If the system determines that it's dangerous to turn left based on the radar data (because a vehicle is coming to the intersection from the north at a high speed, for example), it will notify the driver to stop turning left. This cooperative vehicle-infrastructure is a flexible yet sensible solution that could be deployable in the near future.

Multivehicle cooperative driving and intersection control

Individual-vehicle-control research focuses mainly on guaranteeing driving safety. Increased traffic congestion is making multivehicle-control research an important topic. In 1991, the emphasis was on vehicle platoon control. Then, in the mid '90s, researchers started examining lane-changing- and lane-merging-control problems. A solution to the former problem is path/trajectory planning technology, which studies how to generate a collision-free driving path or trajectory under constrained vehicle dynamics. On the basis of these studies, researchers now consider cooperative driving with intervehicle communication to be a more promising answer to the problem of traffic jams and collisions.

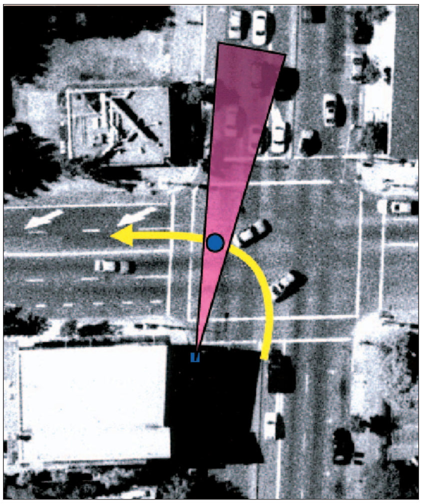

Figure 4. A field observation site for the radar at an intersection.[11]

The concept of cooperative driving was first presented by JSK (Japan's Association of Electronic Technology for Automobile Traffic and Driving) in the early 1990s. Using appropriate intervehicle communication to link vehicles, cooperative driving lets vehicles safely change lanes and merge into traffic, improving traffic control performance. Since then, many others studies have addressed the feasibility and benefits of cooperative driving—for example, California's PATH project (Partners for Advanced Transit and Highways, www.path.berkeley.edu), the European Union's Chauffeur project, and Japan's Demo 2000 Cooperative Driving System (www.ahsra.or.jp/index_e.html).

The latest reports extend cooperative-driving technology to road intersections, which is more complex than lane changing and merging problems. For example, Li Li and Fei-Yu Wang have analyzed how intervehicle peer-to-peer communications help vehicles near an intersection collaborate with each other.[12] They view each vehicle

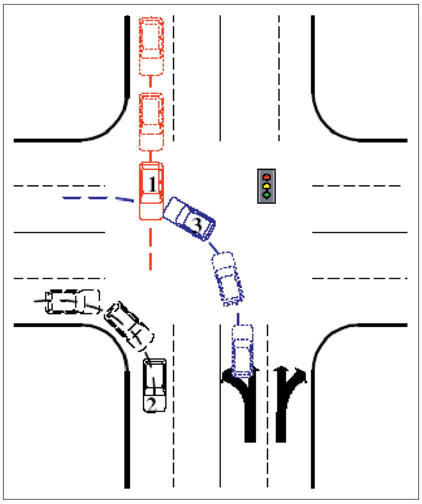

Figure 5. Cooperative route contention at intersections.[13]

as an individual agent and determine the proper driving schedule through negotiation and planning. Then they modify virtual-vehicle mapping and the trajectory-planning method to handle the collision-free requirements and vehicle (dynamic and geometric) constraints. They also have discussed communication-grouping algorithms, but further discussions are still needed, especially for multilane-driving scenarios.

Yiting Liu, Ümit Özgüner, and E. Ekici have proposed a three-level Intersection Warning System with a distance-based warning message generator (see figure 5).[13] Each vehicle approaching the intersection transmits its movement information and driving plan to the repeater installed at the intersection's center. The repeater then forwards or transfers such information to other vehicles and to the IWS. Simultaneously, the IWS generates the warning message based on the received information and broadcasts it to all the vehicles via the repeater.

Driver and passenger assistance

Conventional research has focused on how to make the drive more comfortable—for example, designing advanced suspension and chair systems to avoid injury and implementing smart air-conditioning controllers that adjust the vehicle's inside temperature. More recent research addresses how to

- monitor and analyze the driver's state,
- design an advanced vehicle and user interface to more effectively exchange information, and
- monitor drivers' behaviors to study, evaluate, and even mimic driving habits.

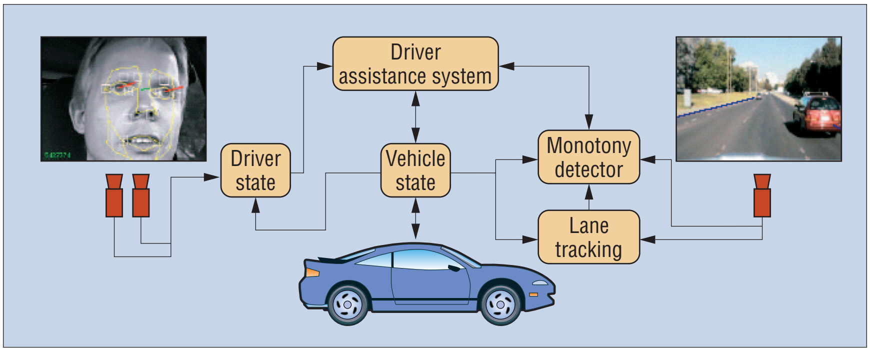

Figure 6. The driver assistance system architecture.[14]

Advanced driver assistance systems should be able to ensure that the driver's reactions are appropriate and safe.

Monitoring driving behavior

The driver's diminishing vigilance level has become a serious traffic safety problem. The National Highway Traffic Safety Administration (NHTSA) estimates that, in the US, drowsy drivers cause 100,000 accidents each year, resulting in more than 1,500 fatalities and 71,000 injuries (www.aaafoundation.org/resources/index.cfm?button=drowsyfaq). Among different approaches in this field, monitoring the driver's head position has received considerable interest. This could help us detect and infer the driver's fatigue level (especially when combined with a driver-eye-gaze tracking system) and implement a "smart" airbag.

Luke Fletcher, L. Petersson, and A. Zelinsky have proposed a novel idea for inferring driver fatigue, studying the relationship between road scene monotony and driver vigilance.[14] Their idea comes from a psychology perspective that defines monotony as an exogenous contributing factor of fatigue. They propose an integrated fatigue detection system that uses driver-head-pose and eye-gaze tracking as well as road monotony analysis (see figure 6). They claim that this system has better performance than those that focus on driver-head-pose and eye-gaze tracking only.

The NHTSA also pointed out that although airbags saved over 6,000 lives by the end of 2000, they also killed over 200 occupants through inappropriate deployment (www.iihs.org/safety_facts/qanda/airbags.htm). In response, the NHTSA issued a set of regulations mandating smart airbags that can adapt intelligently to the occupant. The head position algorithm must be robust to lighting conditions and uncontrolled driver postures. Infrared cameras can help eliminate the disturbance of poor lighting conditions. Algorithms can help reject occlusion and the presence of other competing head-like objects in the scene. For instance, Stephen Krotosky, Shinko Cheng, and Mohan Trivedi have proposed a special algorithm to constrain the relative size and disparity of an occupant's head in order to model and validate the potential heads in the camera image.[15] Results of ground truth experiments show that the detected head location can accurately estimate the occupant's 3D location. The demo system was robust to harsh lighting, partial occlusions, and competing objects such as hands (see figure 7).

Advanced user interface design

Intelligent assistance systems can present drivers with more information—for example, using smart tire-monitor sensors. As a result, information display placement and viewing methods are also hot topics. Bernard Champoux has proposed an interface to maximize information representation by collapsing many of the separate dashboard controls, displays, and systems into a single multifunction display (MFD).[16] A more challenging idea he has proposed is to switch the representation of information to match different driving situations (city versus highway driving, for example). However, static displays have their own advantages; information is always in the same place and format. Transferring to MFD will break this rule and introduce learning and usage trouble.

Solving this problem will require significant research into driver ergonomics. Also, results from aviation assistance might be useful.

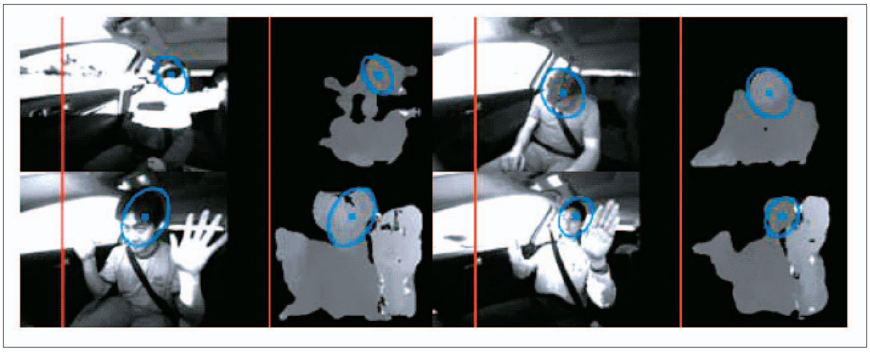

Figure 7. Successful detection for difficult examples: the captured images and the disparity images. The detected head location is shown in blue.[15]

Examining all these IVS 05 papers suggests that intervehicle, vehicle-roadside, and vehicle-driver information sharing is currently the most attractive trend in intelligent-vehicle research. Consequently, an important problem we'll need to solve is setting up communication protocols so that products from different manufacturers can communicate with each other. No single company or institution can provide a complete intelligent vehicle, so interoperability among varied sensors and actuators emerges as a great new challenge.

Acknowledgments

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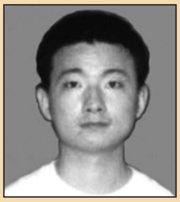

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