A Survey of Intelligent Vehicle Applications Worldwide

Richard Bishop
Richard Bishop Consulting
P.O. Box 80
Granite, MD 21163
USA
410-461-8067 v / 410-461-8173 fx
RichardBishop@mindspring.com

Introduction

The field of intelligent vehicles is rapidly growing worldwide, both in the diversity of applications and in increasing interest in the automotive, truck, public transport, industrial, and military sectors. These systems offer the potential for significant enhancements in safety and operational efficiency. As one component of ITS, Intelligent Vehicle (IV) systems use sensing and intelligent algorithms to understand the environment immediately around the vehicle, either assisting the driver in vehicle operations (driver assistance) or fully controlling the vehicle (autonomous). Following the success of information-oriented systems, IV systems can be seen as the "next wave" for ITS, functioning at the control layer to enable the driver-vehicle "subsystem" to operate more effectively in the highway environment. This article provides a broad overview of applications and selected activities in this field.

IV Application Areas -- IV application areas can be readily segmented into a) systems which provide an advisory/warning to the driver (collision warning systems), b) systems which take partial control of the vehicle, either for steady-state driver assistance or as an emergency intervention to avoid a collision (collision avoidance), and c) systems which take full control of vehicle operation (vehicle automation). Collision warning systems include functions such as forward collision warning, blind spot warning, lane departure warning, lane change / merge warning, intersection collision warning, pedestrian detection and warning, backup warning, rear impact warning, and rollover warning for heavy vehicles. A special category of collision warning is driver monitoring, to detect and warn of drowsiness or other impairments which prevent the driver from safely operating the vehicle. If the driver does not adequately respond to warnings, collision avoidance systems take control of the steering, brakes, and/or throttle to maneuver the vehicle back to a safe state. Driver assistance systems include functions such as adaptive cruise control, lane-keeping, precision docking, and precise maneuvering. Vehicle automation systems include low speed automation (for congested traffic), autonomous driving, and close-headway platooning (which provides increased roadway throughput); also, electronic vehicle guidance in segregated areas such as busways and freight terminals. These systems can be implemented as autonomous systems, with all instrumentation and intelligence on-board the vehicle, or as cooperative systems, in which assistance is provided from the roadway, or other vehicles, or both. Roadway assistance typically takes the form of passive reference markers in the infrastructure. Vehicle-vehicle cooperation enables vehicles to operate in closer proximity to each other for purposes of increased efficiency, usually by transmitting key vehicle parameters and intentions to following vehicles. The general philosophy is that autonomous systems will work on all roadways in all situations to a useful level of performance, and take advantage of cooperative elements, as available, to augment and enhance system performance.

Key Supporting Technologies. -- While many types of technologies can support the functions listed above, a few specific technologies are consistently emerging for diverse research programs worldwide. These are:

- Machine vision -- Image processing is advancing rapidly in support of multiple industries, and IV systems are taking full advantage. Video cameras are attractive from a packaging and cost perspective, and the computer processing hardware is available, with Application Specific Integrated Circuits geared to image processing nearing availability. Machine vision supports both lane detection and vehicle following
functions, as well as obstacle detection to a lesser extent.

- **Radar** – Radar systems to support adaptive cruise control will enter the market rapidly over the next several years, providing a ready on-board sensor to support other functions. The long-range ranging capability and azimuth accuracy of radar provides ample data as to the roadway scene ahead of the vehicle, and algorithms are increasingly robust in discriminating targets of interest (objects in the forward path) from clutter (objects off road or vehicles in adjacent lanes). Radar systems are expected to converge on a frequency of operation in the 77 GHz region, as this is the current European standard.

- **Magnetic referencing** – Magnetics provide a robust, all-weather means of indicating lane boundaries, to supplement machine vision techniques. Commercially available magnetic highway lane marking tape or discrete markers are in use or planned for several deployments. Because the magnetic reference must be installed on the roadway, initial deployment is expected to focus on spot applications.

- **High-accuracy digital maps and GPS** – Major digital mapping companies are working with the automotive industry to define new levels of accuracy which could assist IV systems, such as providing road curvatures and lane configurations, as well as lane boundaries to accuracies sufficient for lane-keeping. Centimeter-level GPS techniques would be employed to detect the vehicle position and key the digital map to augment information provided by sensors.

### Passenger Car Applications

Passenger car applications offer substantial benefits due to the hundreds of thousands of deaths and injuries that occur worldwide due to highway accidents. Because of the need to minimize false alarms and maximize reliability for this consumer market, introduction of passenger car systems is proceeding slowly, although steadily.

**Collision warning** -- The collision warning systems listed above have been extensively prototyped and tested. Night vision and backup warning systems are now available on some automobiles, and Mitsubishi and Nissan have announced the near-term availability of collision warning packages. Forward collision warning and lane departure warning are expected to become available in the next 1-2 years. The Japanese Smartway concept will implement user services such as lane keeping, intersection collision avoidance, pedestrian avoidance, and headway keeping. A model deployment project is planned to be operational by 2003, with nationwide implementation in 2015. A major proving test and public demonstration, called SmartCruise 21, will be sponsored by the Japanese government and the Advanced Cruise-Assist Highway System Research Association in late 2000. European Commission funding is also supporting research in longitudinal and lateral collision warning, and the U.S. IVI program is establishing a partnership with key automotive manufacturers to perform pre-competitive research in the areas of human factors (driver workload), use of high accuracy digital map databases, and development of metrics and testing methodologies for collision warning/avoidance products.

**Collision Avoidance and Driver Assistance** -- The high-profile driver assistance product is Adaptive Cruise Control (ACC), now available in Europe and Japan and soon to be introduced in the U.S. (ACC senses slower vehicles ahead and adjusts speed to establish a safe following distance, resuming the desired speed when the way ahead is clear.) Current ACC systems are geared for highway speeds; the next generation systems (now in testing) will also support stop-and-go congested conditions. In 1999, Mitsubishi introduced its new Driver Support System in Japan, which supplements ACC with lane departure warning and side and rear monitoring via machine vision. Honda, Nissan and Toyota have developed several safety subsystems within the joint Advanced Safety Vehicle project, including lane positioning, headway control, automatic braking, obstacle warning, drowsiness warning system, and nighttime pedestrian warning. Publicly funded research in Europe is focusing on driver monitoring, road condition sensing, vision enhancement, heading control, and sensor fusion. USDOT has begun a five-year, $35M project with General Motors to develop and test pre-production rear-end collision avoidance systems.

**Intelligent Speed Adaptation**
Several countries are testing Intelligent Speed Adaptation as a means of increasing safety. The system concept calls for automatic control of maximum speed of the vehicle, through signals from
the roadside or from satellite positioning coupled with on-board maps which include speed limit information for specific roadways. A major trial involving over 7,500 vehicles is underway in Sweden, and similar, although smaller, tests are happening in the Netherlands, the United Kingdom, and Korea. Accident reductions in the range of 20% are postulated with the mandatory use of these systems, whose feasibility in the public eye is strongly dependent upon the prevailing culture and attitudes about government control.

Automated Operation -- Fully automated vehicle operation offers the advantages of safe travel, more efficient traffic flows, and convenience to the driver. This capability has been prototyped and demonstrated extensively during the nineties, establishing technical feasibility. Current research focuses on refining system approaches. Fully functional automated cars, developed by the University of Korea, the Mechanical Engineering Laboratory in Japan, the University of Pavia (Italy), Ohio State University, and the University of California, among others, are currently being tested and refined. For the nearer term, Low Speed Automation (LSA) is expected to be very popular as a convenience item. LSA would be engaged in slow-speed congested traffic conditions, so that the driver can relax instead of controlling the vehicle under these tedious conditions. When the congestion clears and speeds increase, the driver would resume control. This capability is being developed in both Asia and Europe.

Heavy Truck Applications

Collision Warning -- The heavy truck market represents the ideal industry for early implementation, as costs resulting from collisions represent a major drain on profits. Current prices for CW systems, while high by consumer standards, are viable for the truck market. It is estimated that over 50,000 radar-based collision warning systems are now operating on heavy trucks in the U.S., with annual sales of around 10,000 units. Trucking companies, generally self-insured, suffer costs averaging around $20,000 for even a minor accident, and costs can easily exceed $100,000 for a major accident; many users of these collision warning systems have reported substantial accident reductions, quickly recovering their approximately $2000 per unit investment. Similar units are expected to become available soon in Europe and Asia. Lane departure warning systems became available in 1999, based on machine vision techniques which interpret the road scene to detect the edges of the travel lane. Daimler-Chrysler has announced that this feature will be available on trucks sold in Europe and the U.S. in 2000. The U.S. IVI program has initiated three operational tests focusing on collision countermeasures for heavy trucks -- Freightliner Corporation is testing a Rolllover Stability Advisor/Controller device; Mack Trucks is testing Infrastructure Assisted Hazard Warning (IAHW), Lane Departure Warning, and Automatic Collision Notification (ACN); and Volvo Trucks is evaluating Forward Collision Warning, Blind Spot Warning, Adaptive Cruise Control, and Electronic Braking Systems. In parallel, the US DOD, with a fleet of over 400,000 trucks, is sponsoring intelligent vehicles R&D via their 21st Century Truck initiative, with initial projects expected to begin in late 2000.

Driver Impairment Monitoring -- USDOT has a highly active program is developing drowsy driver countermeasures for the trucking industry, as fatigue plays a major role in truck accidents. Research has focused on understanding fatigue factors in driving, defining measurable physiological parameters, development of in-vehicle systems which can unobtrusively monitor the driver, and development of warnings and techniques to help the driver regain alertness. Testing of a variety of system approaches is currently being conducted. Private sector activity is ramping up, as well, in development of products which provide relative indications of driver fatigue. The Assistware SafeTrak product, for instance, provides a "score" to drivers based on a running average of the lane tracking accuracy (measured through video image processing): the system is based on the empirical principle that "wander" in the lane increases as fatigue increases.

Collision Avoidance and Driver Assistance -- Collision avoidance systems will follow successful experience with the collision warning systems described above. Forward collision warning alerts can be enhanced with brake activation, and the ability to provide precise, and differing, brake forces at individual wheels opens the way to Electronic Stability Control (ESC) which has great potential to reduce rollovers. ESC is expected to become available in Europe by 2001, with slower implementation in the U.S. ACC was introduced for trucks in the U.S. in 1999 and all U.S. truck manufacturers are actively integrating this capability
into their standard product line. In evaluations of
ACC, truckers report that fatigue is substantially
reduced and fuel savings are achieved.

**Automated Operation** -- Daimler-Chrysler, Renault
VI, and IVECO are participating in the
CHAUFFEUR project to develop an electronic tow-
bar capability to enable close-headway convoying of
heavy trucks, with following trucks fully automated.
Three scenarios, each with increasing complexity, are
defined:
- Convoying of two trucks, with a driver only in
  the first truck
- Convoying of multiple trucks, with a driver only
  in the first truck
- Convoying of multiple trucks, with no driver at
  all – all driving is automatic

The concept calls for continuous communications
from the lead truck to following trucks, as well as
image processing from IR and video cameras in the
following trucks to stay locked on to their target.
Initial capability of a two-truck convoy was
successfully demonstrated in 1999, with the driver in
the following truck turning over control to the
automated system. A follow-on CHAUFFEUR II
project has now been funded, whose goals include the
development of a more robust system and the ability
to convoy three or more trucks. Additionally, the
University of Minnesota has developed their
SafeTruck concept, which provides for a “virtual
bumper” around the truck based on sensing data.
Alerts are provided as needed, and if the driver loses
control, the system intervenes, drives the vehicle to
the shoulder, and stops it.

**Bus and Public Transport**

**Applications**

**Collision Warning** -- Collision warning activities for
buses are only occurring in the U.S. currently, under
the IVI program. While bus accidents do not result in
large numbers of severe injuries or fatalities, the
economic costs of minor accidents are substantial
(estimated at $800M nationally). The FTA is
working with local transit agencies to develop
performance specifications for lane change, forward,
and rear impact collision warning.

**Collision Avoidance and Driver Assistance** --
Collision avoidance systems for buses will be a
natural follow-on to successful implementation of
collision warning systems. A key driver assistance
feature is precision docking, which enables a bus to
consistently pull up to a bus stop with a minimal gap
from the edge of the bus door to the curb. This
seemingly innocuous capability optimizes the flow of
passengers and prevents mishaps. Precise docking
has been demonstrated using both machine vision and
magnetic referencing. Transit agencies worldwide
are actively interested in this application, with initial

**Automated Operation** -- Electronic guidance of buses
offers the people-carrying capacities approaching that
of a light rail system, without the capitol costs
required with rail. Due to space restrictions in urban
areas, many times only very narrow exclusive bus
lanes can be defined, and electronic guidance enables
the bus to precisely track within its designated lane at
full speed. Electronically guided bus systems are
now being implemented in the Netherlands, France,
England, and Japan. In France, the CiViS system
concept, developed by IrisBus, has been selected for
implementation within the cities of Clermont-
Ferrand and Rouen. CiViS relies upon a visual
stripe denoting the path of the bus and on-board
image processing to track the stripe. In England,
London Transport implementing electronically
guided bus service to the Millenium Dome at
Greenwich and the surrounding area, with initial
service planned for 2002. Within the U.S., several
transit agencies are planning or considering
electronic guidance systems, with support from the
federal Bus Rapid Transit (BRT) program.
California DOT is actively developing automated
buses, with a demonstration planned for 2002.
Guided bus systems are also under consideration in
Sao Paulo, Brazil and other South American cities.

**Rubber-Tired People Movers** -- People movers are
now operating using automated techniques: at
Schipol Airport in Amsterdam, the unmanned
ParcShuttle implements a “horizontal elevator”
concept, picking people up at remote parking sites
and taking them to their desired terminals, using a
free-ranging-on-grid technology approach. Another
ParkShuttle system serves a Rotterdam office park.

**Special Vehicle Applications**

Current work in the special vehicle arena focuses in
the areas of snow removal operations for highway
maintenance, automation of repetitive vehicle
movements within industrial complexes, and
autonomous vehicles for military operations.
Collision Warning – California and Minnesota are testing evaluation systems to provide lane-edge indications to snowplow drivers attempting to clear roads in low or zero-visibility conditions resulting from high winds or blizzards. The systems rely on the application of magnetic referencing to the highway, indicating the position of each lane, or on highly accurate digital maps and precise GPS positioning on-board the plow trucks, to provide lane tracking. In each case, the plow truck driver remains in control of steering and keys off a display indicating the lane edge. The USDOT IVI program has awarded an operational test to the Minnesota DOT to provide expanded testing of these techniques.

Automated Operation – For snow removal, California DOT has plans to develop an automated snowblower, to operate in an unmanned mode in dangerous mountain passes.

Industrial Automation – At seaports, shuttling of transport containers is typically done by “yard tractors” which take on containers at shipside and transport them several hundred meters away to a storage area. This highly repetitive vehicle operation has been automated within the port of Rotterdam, with free-ranging-on-grid transponder technology. Other ports worldwide are currently considering implementing this type of system. Additionally, large industrial complexes may have substantial freight movements between on-site facilities, which are typically served by trucks. The Combi-Road system, developed in the Netherlands, provides for unmanned tractors operating on a dedicated path to carry freight back and forth between such points. Magnetic lateral referencing is employed, along with an array of optical beacons to detect obstacles. Implementation is now under discussion for an industrial site in southern Holland, and the Dutch government is considering this approach for transporting freight out of the Port of Rotterdam and distributing it throughout the country via special lanes constructed alongside the public highways.

Military Operations – The U.S. Department of Defense seeks to deploy unmanned vehicles for hazardous military scout missions. The current third generation program, called Demo III, calls for highly capable vehicles operating cooperatively both on-road and off-road. Requirements for on-road operations create an overlap with intelligent transportation systems, and useful spinoffs to the automotive and truck industries are expected. The vehicles must operate both singly and in convoys on highways at up to 65 km/hr. and off-road at up to 32 km/hr. The Demo III sensor suite includes a forward looking 77 GHz FMCW radar, stereo machine vision (separate color, monochrome, and infrared cameras) with gaze control. LADAR, 2 GHz foliage penetrating radar, and rear vision cameras. Initial on-road operations are planned for demonstration in late 2000, with full capability achieved at the conclusion of the program in 2001. Also for military operations, the PRIMUS vehicle development program in Germany utilizes substantial machine vision capabilities, using a two-axis platform for gaze control of a color camera. 50 km/hr on-road and 10 km/hr off-road operations have been achieved. With LADAR sensing in use for obstacle detection.

Summary

Looking across all of the activities described above from a time phasing perspective indicates that a steady stream of research and deployment will be occurring over the next several years. The year 2000 will see significant Japanese activity with their “proving test” of Smart Cruise 21 late in the year. Adaptive Cruise Control for automobiles will be gaining in popularity during this time, as well. Attention may begin to turn to the evaluation results of the USDOT operational testing of heavy trucks around 2001, and initial implementation of driver assistance and automation for bus transit in the 2001-2004 timeframe. California plans to demonstrate fully automated trucks and buses in 2002, and Low Speed Automation is planned for initial capability in 2003 in Europe, and could very likely be commercially available shortly thereafter in Europe or Japan. By 2010, USDOT is seeking a 50% reduction in crashes involving heavy trucks and Japan is aiming to achieve a 15% reduction in motor vehicle accidents. The Japanese Smartway concept is planned for full implementation by 2015, and Korea has targeted 2020 for achievement of vehicle-highway automation. All players are looking to deployment as an evolutionary, incremental process.

A key benefit of bus transit and special vehicle deployments is to raise awareness and confidence in the public regarding these systems, which will stimulate consumer demand and public support for government initiatives and provision of supporting infrastructure. Deployment of systems on heavy trucks will provide substantial “real world” testing to
aid in the refinement of systems for the automotive consumer market.

Overall, the question of “should we implement these systems” appears to have been satisfactorily answered – the benefits are well understood by government transportation officials, demonstrations have established credibility and technical feasibility, and the vehicle industry sees a ready market in its customer base. Thus, attention is now on the question of how to best implement the systems. The supporting technology is fairly mature and work is focusing on choosing the best mix of technologies and adapting them for the vehicle-highway environment, optimizing the human-machine interface, defining workable deployment paths, and cultivating government-industry cooperation to accelerate deployment. Clearly, the “next wave” of vehicle innovations is reaching the shore, offering more efficient movement of goods and safer, less stressful driving.

References

1. Intelligent Vehicle Quarterly, Volume 1, Issue 1, Spring 1999: selected articles.

About the Author:
Independent consultant Richard Bishop (RichardBishop@mindspring.com) provides support internationally in business strategy and partnership development for intelligent vehicle applications of all types. He also provides in-depth information on government programs, industry developments, and research results via the internet at www.IVsource.net.