Present and future of Intelligent Transportation Systems

Claude Laorgeau
Professor – MinesParisTech
Robotics Centre - JRU Lara
claude.laorgeau@mines-paristech.fr

ABSTRACT

The word automobile is the French word for car which means mobile on its own and not pushed or pulled by animal force, but actual cars are still controlled by human drivers. The driverless car is a highly automated vehicle which can be used to transport people or goods but without a human driver. Such vehicles don’t really exist at the time but (if and) when they will exist we shall have to change the vocabulary and may be to call them “robocars” or “cyber cars”. Research in ITS laboratories and many emerging improvements proposed by car manufacturers in new generations of vehicles are oriented towards that objective. We analyze the present situation and try to anticipate what the future will be.

Key-words: Intelligent vehicle- Embedded systems- ADAS systems - Generic prototyping tools - Data fusion- V2V & V2I Communications.

INTRODUCTION

The perimeter of robotics has never been clearly defined but is larger than information and communications technologies. A robotics system is a technological entity which has perception, decision, and action and eventually communication functionalities, and which interacts with a physical environment to replace totally or partially a human being. The bottleneck of robotics is generally perception and situation analysis.

If we consider transportation systems we can assume that a car is a mobile robot which has its energetic autonomy but not yet its decisional autonomy. Driverless trains or tramways already exist in many countries. We can augur that in the next decades, the advanced driver assistance systems which already exist will converge to a driverless car in certain situations.

Since there are near one billion vehicles in the world, may be cyber cars will be the next wave of mobile robots.

WHAT ARE THE MAIN PROBLEMS OF TODAY’S AUTOMOBILES

The auto industry is a world-class industry, which drives economic growth in every major country in the world. The auto industry remains a growth industry, with a remarkable 30% + growth rate in the past decade.

The world’s automobile industry makes about seventy million cars, vans, trucks and buses per year. These vehicles are essential to the working of the global economy and to the well being of the world’s citizens.

Worldwide, an estimated more than 50 million people earn their living from cars, trucks, buses and coaches. Auto manufacturers support many supplier industries such as steel, glass, plastics, computers and more.

This powerful industry that pulls the world economy is only one century old. The vehicles alone are without value if there is not a major road network to deliver a safe and smooth traffic.

The three main problems we have to tackle to day are undoubtedly:

- Energy consumption
- Safety
- Mobility and congestion

Energy consumption

There are about 900 million vehicles in the world at the moment. But about 70% of these vehicles are mainly located in rich countries: North America, Europe and Western Pacific (Japan, Korea).

In these countries there are about 60 vehicles for 100 inhabitants. Let us suppose that China reaches this ratio of car penetration...That requires, for China only, the total world stock of vehicles.

Although automakers have invested hugely in developing diverse automobiles that run on alternative fuels like clean diesel, biodiesel, ethanol, hydrogen, and compressed natural gas or that runs on hybrid technology using both conventional combustion engines (gasoline or diesel) and electric engine, that seems to day non realistic since reserves of fossil fuels are limited.

Most car owners do not use their cars more than one hour per day and often less. Yet a car represents a considerable investment expressed as a number of months of work, ranging from ten
months in rich countries to ten years in poor countries. What entrepreneur would accept such a misuse of his investments?

**Carpooling and car sharing** are partial solutions. Car sharing helps reduce congestion and pollution. Replacing private automobiles with shared ones directly reduces demand for parking spaces. The fact that only a certain number of cars can be in use at any one time may reduce traffic congestion at peak times. Even more important for congestion, the strong metering of costs provides a cost incentive to drive less.

**Safety**

There are about 1.2 millions road fatalities in the world per year. But if we detail where those fatalities happened, we notice that approximately only 15% of fatal accidents happen in rich countries while 85% occur in poor nations. For example there are “only” 50 000 fatalities in Europe or in North America per year while there are 220 000 in India.

The paradox is that fatal accidents take place where there are few cars and on the contrary there are fewer where there is an abundance of vehicles. The explanation lies in the poor road network, the ageing fleet and lack of education of drivers.

Despite this paradox it is legitimate to continue research on improving safety. More than 90% of accidents are caused by human failure. So the partial or total automation of driving that ultimately minimizes or even eliminates humans thereby eliminates risks. The ADAS (Advanced Driver Assistance Systems) provide a considerable margin to increase safety.

The new technologies of information and communication offer a large pool of potential progress that we will partially explore.

**Mobility and congestion**

Congestion is caused by an imbalance between supply and demand of circulating surface.

One solution is to lower demand, which is obviously a limitation on social freedom. Road pricing is a system of charging users in periods of peak demand to reduce traffic congestion. Implementation of congestion pricing has reduced congestion in urban areas, but has also sparked criticism and public discontent. Critics maintain that congestion pricing is not equitable, has a negative effect on retail businesses and on economic activity in general, and is just another tax.

Another solution is to increase supply. Increasing the offer is to act in a quantitative manner by continuing to build new roads, bridges, tunnels. The construction of new infrastructures is both very expensive and punitive to the environment.

A third way is to increase the productivity of existing network.

Each parked vehicle occupies a floor space of eight to ten square meters. This surface which can be private (parking or garage) or public has a significant value especially in large cities. But the same vehicle which moves, occupies a "circulating surface" much larger and whose cost is entirely supported by the public.

We imagine each vehicle that moves as surrounded by a security bubble that defines its consumption of circulating surface. This bubble has a maximum width and length that we will seek to decrease. Its standard width is 3.5 metres in Europe and four meters in the USA. But almost all cars have a width of less than two metres. There is thus a considerable waste. **Lateral control** allows the cars to drive safely on tracks closer for example 2.2 meters.

So from the standpoint of the public who finance roads, the square meter of road has seen its productivity rise by 50%.

The length of the bubble is representative of the safe distance required between two vehicles. The minimum safe distance is the sum of two terms: a term associated with human reflexes of the driver, a term which express the differential braking capacity of the vehicle and its predecessor.

It is especially the first term that could be reduced significantly by automatic driving. For example, we usually take for the driver a reflex time of 1.5 seconds which corresponds to a safe distance of 30 metres at 72 km / h. This time can be reduced to 0.5 seconds in the event of automatic driving. That reduces the length of the security bubble to 10 meters, divides by three the circulating surface consumed by the vehicle, and multiplies by three the road capacity. It is therefore a minimum increase of 300% in productivity per square foot of asphalt allowed by **longitudinal control**.

By combining the contributions of lateral and longitudinal control, productivity of the rolling surface of an automated road increases by over 400% compared to the current road.

Such progress has often been observed in the history of automation such as agriculture or manufacturing.

It seems inconceivable that history by-pass such important savings.

**ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)**

70% of innovations in automotive industries are related to electronics.

These various systems are usually called Advanced Driver Assistance Systems (ADAS). Their goal is to enhance safety and mobility of road traffic. A large variety of ADAS have been
developed in the laboratories and several of them are already commercially available.
A non exhaustive list is the following:
- Adaptive Cruise Control (ACC)
- Lane Departure Warning System
- Advanced Navigation System
- Automatic Parking
- Night Vision
- Traffic Sign Recognition
- Lane Change Assistance
- Collision warning system
- Intelligent speed advice (ISA)
- Pedestrian protection system
- Visibility sensor
- Friction sensor
- Adaptive light control
- Blind Spot Detection
- Driver Drowsiness Detection
- V2V for car to car communication
- V2I for vehicle to Infrastructure communication
- Emergency Call (eCall)

We have worked on the development of many of them and we present now some of the most significant ones which are already on the market.

**Adapative Cruise Control (ACC).**

ACC is an ADAS which uses either a radar or laser setup to allow the vehicle to slow when approaching another vehicle and accelerate again to the preset speed when traffic permits. Laser-based systems are significantly lower in cost than radar based systems. However, laser-based ACC systems do not detect and track vehicles well in non-ideal weather conditions nor do they track extremely dirty (non-reflective) vehicles very well. Some systems also feature forward collision warning or collision mitigation avoidance systems which warn the driver and/or provide brake support if there is a high risk of a rear-end collision.

Mercedes Benz was the first to offer a radar based system under the Distronic name, but similar adaptive systems are now offered by other manufacturers, Audi Q7, Toyota Lexus, BMW 5 series, Renault Vel Satis...

These early systems were only intended to alert the driver and did not apply the brakes and only controlled speed through throttle control and downshifting. However, this changed with the Honda Acura RL. It features a Collision Mitigation Braking System, which can alert drivers of objects up to 100m ahead, and, if you get closer, it brakes slightly and tugs at your seatbelts. If you still don't react, the RL tightens and locks your seatbelts and brakes hard.

From a control point of view, ACC is in fact a longitudinal control that regulates the speed while maintaining the safety distance. ACC technology is widely regarded as a key component of automatic driving and it is the basic tool for realizing vehicle platoons. In order to better utilize road-space, vehicles are assembled into ad-hoc train-like "platoons", where the driver (either human or automatic) of the first vehicle makes all decisions for the entire platoon. All other vehicles simply follow the lead of the first vehicle.

Adaptive cruise control (ACC) concerns the inter-distance control in highways where vehicle velocity mainly remains constant. Generally CC and ACC can be activated only at speeds higher than 70 kilometers per hour. Stop-and-Go has the same objective as ACC but deals with vehicles circulating in cities with frequent and sometimes hard stops and accelerations.

It is easy to understand that both situations present completely different comfort and safety constraints, and therefore, that in most of the reported work, ACC and Stop-and-Go problems are treated separately. Stop-and-Go is in fact much more complicated than ACC at high speed, which explains that there are not yet commercially available solutions.

**Lane Departure Warning System (LDWS)**

LDWS is an ADAS designed to warn a driver when the vehicle begins to move out of its lane unless a turn signal is on in that direction. LDWS is normally activated on freeways and arterial roads.

The first production of LDWS system in Europe was the system developed by Iteris for Mercedes Actros commercial trucks.

The system is now available on trucks in North America and in Japan. In these systems, the driver is warned of unintentional lane departures by an audible rumble strip sound generated on the side of the vehicle drifting out of the lane. If a turn signal is used, the system understands that the driver intends to leave the lane and no warnings are generated.

In Europe Citroën first offered LDW on their 2005 C4 and C5 models, and now also on their C6. This system uses infrared sensors under the front bumper to monitor lane markings on the road surface. A vibration mechanism in the seat alerts the driver of deviations.

Many car manufacturers, GM, BMW, Toyota, Volvo also commercialize these systems.

LDWS is limited to alert warnings but, on the Lexus LS, this system allows the vehicle to issue audiovisual warnings and apply corrective steering responses to steer the vehicle back in its lane. From a control point of view, LDWS is in fact a lateral control that maintains the vehicle in its lane. LDWS technology must also be regarded as a key component of automatic driving.
On board signaling

Navigation results from the fusion between a precise localization system using GPS and odometers and a map matching operation which position the vehicle on a digital map. The digital map is in fact a graph and navigation uses a routing algorithm between the starting point and the arrival point similar to those used for electronic circuits. The road database is a vector map of some area of interest. Street names or numbers and house numbers are encoded as geographic coordinates so that the user can find some desired destination by street address. Points of interest (POI) will also be stored with their geographic coordinates. Points of interest include speed limit panels, road safety cameras, fuel stations, hotels, restaurant parking, and hospital. This is what we call the first generation of navigation or static navigation, since we take into account the geometry of the road network but not traffic density.

If we can measure the density of traffic on the different segments of the road network, we can modify the impedance of the network and the routing algorithm will take traffic into account and deliver to the driver an optimum path…this is what we can call dynamic or contextual navigation. Such systems can receive and display information on traffic congestion and suggest alternate routes. These may use either RDS/TMC which delivers coded traffic information using radio or by GPRS/3G data transmission via mobile phones. Real-time data Traffic information also includes:

- Real-time data about free/full parking
- Nearest public transport lines and prices to reach a destination, in order to allow multimodal optimal journey.

This defines the second generation of navigation systems.

We can imagine enhancing the navigation system by introducing a third generation. If we fuse information delivered by various on board sensors such as GPS, radar, lidar, camera …and other vehicles using V2V communications, “On board signaling” becomes the technology which allows presenting to the driver smart messages about the driving situation. We can also call it an electronic co-pilot.

PROTOTYPING AND INDUSTRIALIZING EMBEDDED ADAS

Generic software platform for prototyping ADAS systems

State-of-the-art automotive and more generally robotics systems must embed many sensors. In order to manage the variety of embedded sensors and applications, the need for a modular software framework appears very clearly. We’ll describe the requirements for such a framework, which are fulfilled by the RTMaps platform initially developed in our lab and industrialized now by the Intempora Company.

Modularity is necessary in any development framework to assure:

- capitalization and re-use of the developments
- step by step developments with incremental upgrades
- quick and easy evolution of the applications (easy switching of sensors, algorithms, without having to take apart and rebuild the whole software)
- cooperative team work

Apart from that, it is often difficult to develop and test applications directly on a real system (an equipped vehicle or a robot): it is costly and time consuming for hardware maintenance reasons, material immobilization, and for comfort issues as well (who likes developing software standing up next to the system with the keyboard in one hand and a screen somewhere far away…). This makes it necessary to use tools that can bring a hardware abstraction layer simulating the system on a desktop environment, and that can also facilitate porting desktop developments to the real-system (back and forth). This software environment must finally enable very quick and easy integration and testing of algorithms, easy management of multi-tasking and distribution of processing.

RTMaps has been designed to meet such requirements in that its modular architecture allows easy development of independent building blocks (also called RTMaps components) and provides integrated functionalities for recording time stamped sensor data flows and replaying them in a desktop environment in order to simulate the real-system. It was built upon the experience of researchers and engineers in multi-sensor algorithms for perception and meets a lot of our needs.
All the demonstrations realised in our laboratory use the RTMaps platform for prototyping applications and making them run in our real cars.

**New hardware and software tools for ADAS systems industrialization**

A modern automobile may have as many as 50 Electronic Control Units (ECU) for various subsystems (typically, the biggest processor is the engine control unit; others are used for transmission, airbags, antilock braking system, cruise control, audio systems, windows, mirror adjustment, etc.) and several hundred software functions, interconnected through several communication networks such as CAN, MOST, FlexRay…

Due to the variety of hardware platforms used in this field, ECU software dependence on the hardware and system configurations being used has become problematic.

In order to reduce automotive software complexity, enable software reuse, and establish industry-wide standards, automotive electronics organizations have created the Autosar software architecture. The partnership between the Core Partners was formally signed off in July, 2003 AUTOSAR (AUTomotive Open System ARchitecture) is an open and standardized automotive standard architecture, jointly developed by automobile manufacturers, suppliers and tool developers.

The reusability of software is obtained by separating the application software from basic modules and functions with an abstraction layer approach as show on the preceding figure.

**COMMUNICATIONS**

If we think of the main technical revolutions in the world over the last two decades, we immediately think of Internet and the mobile phone. The massive human to human mobile communications (M2M) that we have observed will be followed by massive object to object (O2O) communications and particularly in transport systems by vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications. Just as nobody could twenty years ago imagine the applications of the Internet, we can not imagine today the development of communications in transport systems. The fast and impressive development of technologies and protocols: WIFI family 802.11, WIMAX, GPRS, UMTS, DSRC, IR-MR, and DAB ... combined with the deployment of IPV6 will change our world. Unlike artificial vision, communications are characterized by high reliability and deterministic behavior. That is why the dissemination of practical applications of communications in transport systems should be faster.

Wireless communications among vehicles and between vehicles and the roadway infrastructure can enable a variety of improvements to transportation system performance. However, there are significant challenges to the widespread implementation of wireless networking among vehicles and roadside devices.

If we deploy an infrastructure for vehicle communications at discrete points along the road side we can think in term of info fuelling.

When we think of info fuelling we have to separate two types of information:

- **permanent information** such as the geometry of the road, the number of lanes, the topology of intersections, the curvature of the bend, the road signs and markings and

- **Context-dependent information** such as traffic density, the weather, local perturbations or road works ……

Both permanent and context-dependent information have to be presented to the driver by means of the adequate human-machine interface. That is what we call on board signing. That means that we do not deploy any automatic decision system but present information to the human driver-decision maker.
To deploy info fuelling, we have to first introduce the concept of info feeding. Concerning permanent information we have to specify the attributes that will be stored in the next generation of road information data bases and also to imagine how this information will be used on board the vehicle, and fused with roadway sensors and GPS, vision, and radar to enhance safety.

Concerning context-dependent information, we have to define the pertinent information that must be presented to the driver, to collect the appropriate data, and to communicate them to the vehicle using a wireless medium.

There are as yet few real applications of V2V or V2I communications since the stakeholders wait for stabilization and a robustification of technologies. Several European projects are already focusing on those topics and particularly big IP (Integrated Projects) such as CVIS, SAFESPOT, COOPERS.

COOPERS has already identified a set of 12 potential applications of V2V and V2I on highway traffic such as for example:
- Accident/incident warning
- Weather condition warning.
- Roadwork information
- Lane utilization information
- In-vehicle variable speed limit Information
- Traffic congestion warning

These examples concern infrastructure to vehicle communications to secure and smooth traffic, others concern services such as:
- Road charging
- Estimating Journey Time
- Automatic road map update

In the frame work of two European STREP projects, we have developed applications of communications for safety and for mobility.

In the REACT project, one of the key ideas was to use a car as a sensor of traffic conditions and to transmit this information using long distance V2I communication such as GPRS.

A human driver can appreciate the traffic and qualify it as fluid, loaded or busy. A smart vehicle has the same information as the human driver. It knows the location of the vehicle through GPS and digital map, the date and time, and a variety of information through the CAN bus such as speed, the gear engaged, the average sliding speed, the state of turn signals, of brake lights, of windshield wipers... By combining this information through heuristics, it becomes possible to describe the state of traffic. The software component doing that task is called a traffic sensor and we have developed such a component in the REACT project. The technical results obtained are correct, but the deployment of this approach needs long distance communications between the vehicle and the regional traffic control center. We decided to improve this approach in the COM2REACT project which followed REACT.

Implementing the REACT model where the cars are thin clients with extremely reduced "intellect" leads in practice to enormous strain on the RCC and cost-intensive information exchange.

The key element of the C2R concept is the introduction of the intermediate VSC (Virtual Sub Center) level in the data exchange, processing and decision structure. There exist many reasons not to keep all data in an information system running under a single authority. Some of these reasons are related to the improved use of resources existing in every car. Another advantage is the possibility to have parallel processing of the data, to combine data and knowledge from (many) different sources in order to create individual interpretations, to support more effective decision process and to avoid bottlenecks. Most of all, a VSC vehicle cluster will be a rather short-lived, temporary structure.

Frequent exchanges of information (not decisions) between members build the redundant data base in every vehicle. That is required to give autonomous, well-informed support to all drivers at any time.

The main features of the VSC system are:
- **Distribution of knowledge:** All vehicles provide their knowledge to their VSC network, in order to make vehicle information systems that were formerly separated work together, and in order to make different interpretations of data available.
- **Autonomy:** Every vehicle is able to take decisions independently. To achieve effective decision making, every VSC member integrates and presents information from a variety of sources.
- **Dynamics:** Changes in the structure of the system and the VSC leader.
- **Scalability:** Achieving scalability through resource and knowledge distribution.

The virtual sub center system is a temporary network of entities (cars) linked to share data, knowledge and access to the RCC. The structure of the system is shown in the figure below. The VSC system works like:
- a „plug and play“ system where each component fits into an existing structure fast and convenient;
- a knowledge sharing community which makes it possible to disseminate the knowledge needed for the decision process;
- a common communication link to RCC;
- a “virtual” repository for all coexisting data sources based on a flexible scheme.
Recently the European Commission has taken two important decisions concerning communications:

- a single EU-wide 30 MHz of spectrum in the 5.9 Gigahertz (GHz) band that can be used for immediate and reliable communication between cars, and between cars and roadside infrastructure has been reserved.
- E Call will be compulsory on new vehicles in Europe in 2011.

CONCLUSION

The dream of a driverless car is very exciting but seems unattainable to day.

From the point of view of the driver, driving a vehicle under normal conditions can be broken down into three main sub-functions:

- Maintaining the vehicle in its lane, typically the right one using the steering wheel as actuator.
- Maintaining a correct speed compatible with the 3D geometry of the road and the presence of other vehicles, using accelerator and brake pedals as actuators.
- Managing overtaking manoeuvres.

The first two functions correspond to lateral control and longitudinal control and are already on the shelf, known as ACC and LDWS. The third already has laboratory solutions, but not a commercial application.

From a technical point of view, the global problem can be broken down into four sub-systems:

- **Navigation**: the car knows how to get to the target location from the present location.
- **Perception**: the car analyses the lane, the road, traffic and interprets its environment.
- **Motion planning**: getting through the next few meters, steering, and avoiding obstacles while also abiding highway code and avoiding harm to the vehicle and others.
- **Control**: of the vehicle itself, that is, acting on car actuators: steering wheel, brakes, accelerator pedal, clutch pedal, indicator signal … ...

The four sub systems have received many substantial contributions in the last decade but the bottlenecks always seem to be perception and scene comprehension.

We will not have a complete solution, door to door unmanned driving system; we probably will have to use a cooperative infrastructure. But we can imagine a hybrid car being driven manually in urban areas and automatically on highways under certain circumstances.

AKNOLEDGEMENT

I would like to thanks my colleagues at the Robotics Research Centre and the Lara team and all Wikipedia contributors who allow ideas mining.

REFERENCES


http://www.autosar.org/find02_ns6.php

https://www.eurtd.org/QuickPlace/project-react/Main.nsf/h_Toc/9dc7ec3c99e93073c1256f22002eb225/?OpenDocument

http://www.com2react-project.org/

DEFINITIONS, ACRONYMS, ABBREVIATIONS

ECU: Electronic Control Unit
RCC : Regional traffic Control Centre
VSC : Virtual Sub Centre
ADAS: Advanced Driver Assistance Systems