Applying Map Databases to Advanced Navigation and Driver Assistance Systems

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Navigation map databases have evolved during the last 10 years in coverage, content and accuracy to such a degree that they are being used (and considered) for applications beyond vehicle navigation. For a number of advanced driver assistance systems (ADAS) in Europe and North America, the navigation maps are being enhanced to offer new functions. This will complement dynamic route guidance, with location referencing, descriptions of delays, floating car data and re-routeing, all requiring developments in traffic management, road capacity balancing and routing algorithms.

KEY WORDS

1. Road. 2. Maps. 3. Telematics. 4. Integration.

1. INTRODUCTION. In-vehicle navigation has become a mainstream product not only in upper-range vehicles but also in mid-range and commercial categories, where its cost and time saving benefits are well recognized, especially in Europe and Japan. As this market matures, there has also been growing interest in other related areas, such as:

(a) Using the map database for creating advanced driver assistance systems (ADAS);
(b) Using the map database as a reference for a variety of other data sources that enable dynamic route guidance to take place.

This paper reviews these applications and considers some related issues that must be addressed.

2. ADVANCED DRIVER ASSISTANCE (ADAS). With the widely recognized requirement to reduce driver distraction and workload, several ADAS concepts are being developed. The first systems offered promised convenience and safety benefits, which has led to further research on vehicle dynamic behaviour and methods to link this to the intended trajectory or travel path. There are new uses for digital maps, both with and without navigation, for a variety of new ADAS solutions, which allow new applications and improvement of those already in use. The following ADAS issues will be addressed:

(a) the application of digital maps to ADAS-based products,
(b) different models for applying digital maps for ADAS,
(c) inherent requirements for accuracy and additional attributes, and
(d) methods to create and update digital maps for ADAS.

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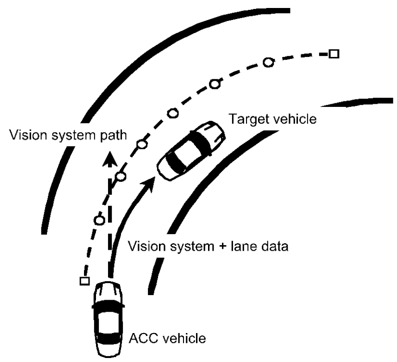

Figure 1. Using digital map data for Adaptive Cruise Control.

2.1. *Digital maps for ADAS.* Anti-lock braking with traction control is an ADAS function with which motorists are already familiar. These systems offer measurable road safety advantages thanks to evolutions in hardware and software, which enable millisecond re-calculation of the vehicle's dynamic state. They are well established and integrate dynamic stability control and emergency braking response features.

Other ADAS applications available in limited production include terrain-dependent gear selection, automatic cruise control (ACC) and night vision enhancement. Other developments, such as headlamp aiming, speed advisory messages and others are in the planning stages. As the research and development (R&D) programmes advanced, it was realized that knowing where the vehicle is heading would be a key enabling technology. This might cover a range of possible safe paths ahead, from which the required trajectory for either a pre-programmed route or some impending manoeuvres could be chosen.

2.2. *ADAS applications under development.* Several vehicle makers are at various stages of R&D into ADAS applications. Notable examples that can or are likely to use an enhanced digital map database include:

(a) Adaptive Cruise Control (ACC).
(b) Headlight direction control.
(c) Curve preview information.
(d) Enhanced night vision.
(e) Intelligent speed adaptation.
(f) Improved emissions and fuel efficiency.
(g) Terrain-dependent gear-selection.
(h) Intersection collision warning.
(i) Run-off road detection and warning.
(j) Front/rear collision warning and avoidance.

Some of these applications are described below to illustrate how the map can be applied as a 'predictive sensor'.

2.2.1. *Adaptive Cruise Control (ACC).* ACC maintains a driver-selected headway, by reducing speed when tracking a slower moving 'target' vehicle. Current ACC systems use a combination of vision and/or radar based techniques. However, as Figure 1 shows, this process poses a special situation as the ACC-equipped target vehicle approaches a curve. The vehicle's ACC must determine whether a curve is indeed ahead, that the target has not simply moved into another lane, and that the road is taking a 'different path'. In such a case, the target should be 'dropped'. This latter scenario may cause an inappropriate resumption of the preset cruise speed.

Clearly, an on-board digital map representation of the road ahead can be of real value as a reference from which to determine not only that a curve is present, but also its radius/geometry. In such a case, if the degree of the target vehicle's shift 'off-beam' remains congruent with the shape of the road ahead, the ACC vehicle's cruise control could act in a more comfortable and predictable manner.

2.2.2. *Night Vision and Headlight Direction.* Night driving on twisting roads (especially in poor conditions), presents added dangers. A driver's failure to estimate properly and adapt to such conditions can lead to loss of control, often also due to excessive speed. By aiming headlights to the right or left, (and eventually downwards as the brow of a hill approaches) in anticipation of the road ahead, the driver's view becomes greatly enhanced. Not only can the ADAS function advise and alert the driver about upcoming curves, but it can also better reveal pedestrians, animals or other potential obstacles, earlier than with today's fixed headlights. In the US, Cadillac offers night vision based on infrared head-up display. The field of view in front of the driver is adjusted from steering wheel inputs.

In such scenarios, an on-board digital map can be used to determine both the direction, and timing of any system adaptation, as well as visible/auditory advisory warnings. In the case of headlights, it is their angular movement (in 2 and possibly 3 planes) in relation to vehicle speed and road geometry ahead that makes the system so helpful. For the head-up display, the area of the scene being covered may be modified to suit vehicle–driver Human Machine Interface (HMI) considerations. This approach is clearly more effective than a mechanical or electronic steering-angle-based alignment, especially when the situation might be critical due to the driver's own confusion about the road ahead.

2.2.3. *Curve Preview Information and Intelligent Speed Adaptation (ISA).* Another attractive solution is to inform the driver via the advanced HMI about upcoming speed limits, hazards and curves. This applies to both day and night driving and enables better preparation and speed management as a driver enters a hazardous road section, a restricted urban area with strict speed limit needs, or a series of curves. Again, this is not possible without a digital map as a look-ahead-reference.

There is considerable ongoing debate about the pros and cons of ISA, with legislators attracted by the apparent traffic calming and accident reduction potential, and vehicle drivers concerned about an infrastructure-based intrusion into the engine/speed controller. The consensus indicates that driver advisories and a haptic throttle pedal are better ways to remind drivers of their responsibilities. One way to achieve this goal for all vehicles is ultimately to have an on-board digital map with all speed limits digitized. Similar conclusions can be drawn about the remaining applications in the list above.

3. DIGITAL MAPS AS AN INDEPENDENT AUTOMOTIVE COMPONENT.

Early work in ADAS applications began by expanding the use of digital maps currently used with navigation systems. It is likely that a navigation system may be already specified in a vehicle platform that is targeted to receive an ADAS application. As ADAS systems are proposed, demands are being made that the digital map should be viewed as an independent automotive component, rather than a simple sub-component or software package. It is clear that such maps offer greater comfort, safety and convenience beyond navigation systems. Therefore plans are being made throughout the automotive industry for the stepwise introduction of ADAS equipped vehicles that do not necessarily have navigation as a foundation system. Nevertheless, synergies undoubtedly exist when both ADAS systems and navigation are present in the same vehicle. Any system which benefits from knowing an intended path will benefit from the navigation system having established a route/path and then sharing this over a vehicle databus with other ADAS systems.

3.1. *Special requirements of a map database to support ADAS.* To take advantage of ADAS concepts, special demands will be placed on the digital map content, its creation, updating and distribution. One fact already recognized by the automotive and transport telematics industry is that it will be a long time (and probably never), before a digital map so completely reflects the road geometry and network accurately, that an ADAS system could rely on the map as the sole reference for the real world. Clearly, other vehicle sensors will be utilized as part of the solution.

Changes in road networks and local regulations take place all the time. There are changes of road geometry, speed limits, road signs, turn restrictions, and access times-of-day, for example. There are temporary closures for weather, accidents or construction. Thus, while a digital map reflects reality to the greatest possible degree at a given moment in time, the cost-benefit equation of frequency and method of updating and distribution suggests that this complex process can never be 100% complete. Industry R&D tests to date with maps specially adapted for ADAS testing indicate that they should be viewed as an important vehicle sensor, providing a source of 'opinion' about the road network ahead. Where this 'opinion' is reinforced by other vehicle sensing devices such as odometer, radar, wheel speed, inertial sensors, and vision systems etc., an ADAS system can then make a confident judgement about the road ahead and how the driver can be assisted.

Using sensor fusion techniques when there are conflicting inputs from a range of sensors for a given driving scenario, the system's 'confidence level' will adapt until it is less than a threshold-established experimental as viable for that particular ADAS system. At this point, relying on advanced HMI techniques, the system must visually (or haptically) 'resign from its duty' until the 'system confidence level' is re-established; that is, the driver will always be in the control loop and remain fully responsible for his actions. This HMI situation is already familiar to drivers with an ABS, which 'advises' the driver through a visual indicator when the ABS is not working properly. With intact ABS, he is also haptically warned that roads are icy, by brake pedal vibrations at speeds when he normally would not expect wheel lock to occur. Significant R&D work still needs to be done to establish the right scenarios and models for when and how to 'allow' the driver to override the system. Much work is underway to establish metrics and HMI methods regarding driver behaviour when ADAS systems are in use.

EU supported programmes (such as the recently completed RESPONSE Project), and standards setting work on HMI in ISO TC 204 and TC 22 Technical Committees, are a positive recognition by the global industry that these issues must be addressed from the outset. The active participation of international law firms and government regulators, plus the interest of insurance companies, in these ADAS related projects is an indication of both the promise and the challenges facing society, as the communications and multi-media revolution spreads applied to the transportation sector.

4. DEVELOPMENT OF DIGITAL MAPS FOR ADAS APPLICATIONS. The form that the digital maps will have to take to support ADAS is different than for navigation alone. The databases contain an enormous quantity and variety of attributes (up to 150 possible for every link) plus information that aids in selecting destinations, points-of-interest, and data to enable turn-by-turn instructions and the display of maps. However, much is redundant for ADAS applications, which demand instead highly accurate geometry (which will assist in even better navigation). Given the potential separate application of digital maps for ADAS as opposed to navigation tasks, the mode of deployment of such maps must be considered. Today, most navigation system maps are delivered on CDs or DVDs and in the rental market, for theft-related reasons; hard disks are also being used. However, system access to those maps is typically only through low-level software embedded in the navigation system and via a media interface also tied to the navigation system. ADAS applications will bring about the following changes:

(a) The map database will probably need simultaneously to serve multiple vehicle systems (a diversity of ADAS functions will enter the market).
(b) Some ADAS will be 'behind' the vehicle's safety and control 'firewall' while others will be 'in front' of it. In the case of the latter, the Automotive Multimedia Interface-Cooperation (AMI-C) Communications Bus Interface will be applied.
(c) The in-vehicle digital map for ADAS may be incorporated into a 'Vehicle Positioning Module', which will inform any ADAS or other system accessing the module, about the vehicle position relative to the digital map, together with the velocity, acceleration, yaw etc., that are important for ADAS functions.
(d) The navigation system may or may not share its map requirements with the ADAS systems.

These considerations taken together create architectural options as illustrated in Figure 2.

4.1. *Positioning Module (PM)*. The PM will perform two main tasks, namely sensor fusion and map matching. Map information would be integrated in the PM and, for security reasons, the map might be protected with its own firewall to allow only properly qualified and validated updates. The PM would also contain rewritable memory to allow the receipt of incremental map updates, directly by wireless communications or from the AMI-C Bus Telematic Gateway.

4.1.1. *Sensor Fusion*. The various sensors inputs such as inertial gyroscopes, GPS, odometer/wheel speed pulses etc. are integrated into a position, velocity, acceleration or higher derivative, with each of these parameters having a known confidence level. Integrating these input 'location opinions' on a special weighted-average basis, results in an opinion and set of sensor values for vehicle position, velocity, acceleration, etc.

4.1.2. *Map Matching*. Once a 'fused position' is calculated, the map can be used to match this position to a geocoded location. The dynamic derivatives are then

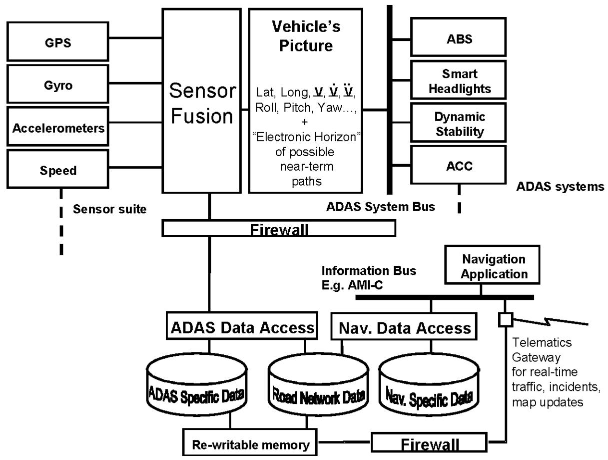

Figure 2. Deployment of digital maps for ADAS.

Table 1. Generalized Approach to Matching Attributes to Functional Requirements in ADAS.

	1st Generation Functions	2nd Generation Functions	3rd Generation Functions
Attribute #1			
Attribute #2			
Attribute #3			
Attribute #i		Specifications, tools and processes enable delivery of this attribute	
Attribute #n			

applied to the location and a complete 'net opinion' of the vehicle's dynamic state in relation to the surrounding road network is achieved. Map matching is a well-established practice in navigation and much of the technology used for that purpose is directly applicable to ADAS. Only when the 'net opinion' is above a given system's confidence threshold can the system start to play an active part.

4.1.3. *Forecasting Dynamic States.* Sampling locations in relation to the road network ahead is of some value, but of much greater value is the knowledge of possible paths/trajectories the vehicle could take. An ideal model would be to use a predefined navigation route or else forecast a most likely path. However, in addition to the likely path, the ADAS system can benefit from knowledge of other possible paths within a given distance or time horizon. An appropriately attributed digital map can offer this, provided it is in a form that can be accessed with the required performance level.

5. DIGITAL MAP ATTRIBUTES. What can be determined about the required attributes for digital maps for ADAS applications? Until recently the automotive industry has been in something of a chicken and egg situation. They want to know what map providers intend to accomplish, and at what cost and timing. On the other hand, map providers are now learning what auto companies are looking for and

are attempting to prioritize the necessary added attributes and features in support of auto company plans.

Recently, a consensus has emerged on some key map attributes and the applications they will enable. Usefully, the first generation of ADAS applications will be based on existing navigation map specifications. However, these specifications will not be suitable for some of the more demanding ADAS applications.

Table 1 illustrates a matrix to show the relationship between each ADAS functionality and map attributes. Generally, the following conditions can exist:

(a) Attributes exist already and are of adequate specification (e.g. speed limits).
(b) Attributes exist already but are of inadequate specification (e.g. road geometry).
(c) Attributes to be added (e.g. curve radii, altitudes and gradients).

Since mid-1999, there has been encouraging collaboration between mapping companies and vehicle builders and, as a closer convergence between ADAS demands and the map builders' capabilities occurs, Tier 1 Electronic/Communications system developers will also become more closely involved. It is expected that ADAS applications development will attract some new system developers who are not accustomed to dealing with digital map databases, or the Auto Industry.

6. GOVERNMENT-SUPPORTED PROJECTS. A number of projects are now addressing map database requirements for ADAS, which involve the main players in Europe; the EU 4th Framework IN-ARTE project was completed in December 2000. It used data fusion for optimised HMI driver-information from ACC and vision systems, using an enhanced Navigation Technologies map database of urban and

rural roads networks in the Paris and Turin areas.

As part of the EU 5th Framework initiative in Europe, starting in mid-2000, the NextMap Project began exploring map data requirements for a broad variety of ADAS applications. Most European car companies are members and have provided a list of database needs to Navigation Technologies and Tele Atlas, the two map providers in the project.

In the United States, the US DOT's Intelligent Vehicle Initiative (IVI) has a sub-project called the EDMAP (Enhanced Digital Map). Approval was granted in January 2001, and the project started in March 2001. Here Navigation Technologies is the sole map provider collaborating with the US car companies to work on this project, which has similar goals to Next Map.

7. INDUSTRY PROJECTS TO DEVELOP ADAS. In addition to government–supported programmes, there are several projects within major vehicle companies in North America, Europe and Japan. To support its customers, Navigation Technologies has developed a specialized effort called the ADAS Research Platform (ADAS-RP) which, when combined with mapping data for a given test area, enables real-world experimentation with ADAS applications.

7.1. *The ADAS-RP*. The ADAS-RP provides customers with a suite of tools, including a set of sensors, the digital map, a data access library and an application support layer able to formulate an 'electronic horizon' of possible 'pathways' which the vehicle might follow. The information generated by the ADAS-RP (currently a

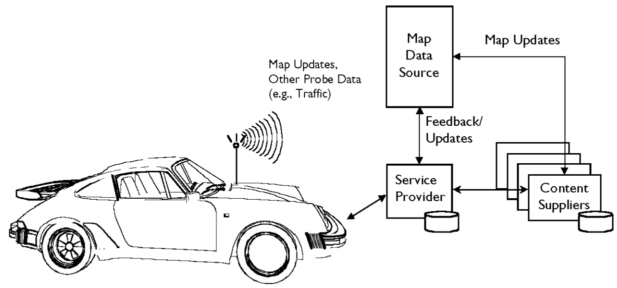

Figure 3. Vehicles as probes.

high accuracy lat-long position, a map-matched location and the 'electronic horizon') is accessible to any vehicle databus (such as the CAN Bus) over which the data can be sampled and used by any ADAS system linked to the bus. From experimental work to date, several of the advanced map attributes needed for different ADAS systems have been identified, as has their level of accuracy and precision.

8. DATA COLLECTION. As the required attributes are better understood, the major task confronting the map supplier is to develop processes for the collecting the required accuracy of data. This requires several questions to be answered, such as:

(a) Can attributes be bundled, in ways that can be applied to corresponding groups of ADAS applications?
(b) Can new methods of geometry capture, such as satellite imaging, be applied?
(c) How can the workload be split between real-time data processing done on the road in specially-equipped vehicles, versus back-office post-processing of the gathered data?
(d) If actual driving is being used with attribute recording anyway, does satellite imaging make sense?
(e) Is error prone automatic post-processing worth doing, as opposed to labour-intensive 'manual methods'?

These are just a few of the questions confronting the map-making industry. Several are themselves the subject of intensive research within Navigation Technologies today and will continue into the foreseeable future.

9. FLOATING CAR DATA (FCD) – VEHICLES AS PROBES. One form of data/attribute gathering possibility that is receiving wide attention for various telematics and traffic management applications is the use of vehicles equipped with (cellular) communications and location technology. These FCD probe vehicles could eventually be the ADAS-equipped vehicles already discussed, but they could also be vehicles equipped with hybrid navigation devices. Given such technology possibilities, positioning data from using FCD-equipped vehicles as probes can provide statistically derived accurate road geometry down to individual lanes, based on numbers of such FCD-vehicles using the same stretch of road. These vehicles could also pass on to a service provider/traffic control centre new road geometry not yet in the database, and such data can be used to to update the base data centrally and to make automatic corrections to errors in the service provider systems. Figure 3 illustrates this usage.

The advantages offered include:

(a) high accuracy (< 50 cms with DGPS), increases with multiple vehicles using same route),
(b) fast updates data sharing among FCD-equipped vehicles, and
(c) position, speed, ambient temperature, road friction and visibility data to be transmitted to a traffic control centre, and shared with all other (equipped) road users.

The issues to be addressed include:

(a) the need for dedicated two-way data communications for GDPS corrections and downloading map/routeing updates,
(b) the very large data processing and traffic management responsibility at control centre,
(c) the minimum number of FCD Probes needed, and
(d) privacy and data protection issues.

Using 'vehicles as probes' will be of only limited value unless the data can be rapidly assimilated, sorted and processed in a central server. This central server will then be able to relay the refined processed map update to any vehicle capable of accepting and benefiting from the update (e.g. for navigation or ADAS purposes).

10. SYSTEM REQUIREMENTS TO USE INCREMENTAL UPDATES. First, a subscribing vehicle will need to have a 'Telematic Gateway' on board, and one or more ADAS/Navigation systems that need the update. This is similar, but not identical to the configuration needed to make a vehicle a probe, and it can be expected that most vehicles will have to meet both functions. Second, the receiving vehicle will need some rewrite memory to receive map updates. Finally, the vehicle's map processing system will need to know when to look for such external updates and traffic information, instead of using the locally stored data that may be out-of-date on read-only media such as CD or DVD.

11. CONCLUSIONS. In this paper, approaches and issues associated with the implementation of driver assistance systems have been examined. The importance of digital maps to enable these functions, and the types of development that need to be undertaken to enable such maps to be used, have been outlined. From this review, it is clear that the digital map is going to be critical for the wider adoption of ADAS and Intelligent Transport Systems in general. The map vendors are working to improve the level of accuracy and to add appropriate attributes. Most vehicle builders have focused R&D programmes, which will lead to a logical introduction of ADAS-based products in the coming years. These efforts are being supported by Government sponsored projects to verify some basic assumptions, and answer some of the open issues. The efficiency and cost-effectiveness of ADAS applications will be both a function of data accuracy at the time the map is built and, because of real-world changes, the degree and methods used to keep the map up-to-date and distributed to the many service providers, motorists and travellers relying on its use.