Advanced Positioning Technology Approach for Co-operative Vehicle Infrastructure Systems (CVIS)

Marius Schlingelhof[1], **David Bétaille**[2], **Philippe Bonnifait**[3], **Philippe Poiré**[4], **Katia Demaseure**[5]

1. German Aerospoace Centre - DLR, Berlin,
phone: +49 30 67055290, e-mail: marius.schlingelhof@dlr.de;
2. Laboratoire Central des Ponts et Chaussées (LCPC), Bouguenais,
phone: + 33 2 40845623, e-mail: david.betaille@lcpc.fr;
3. Heudiasyc UMR 6599, Université de Technologie de Compiègne,
phone: +33 3 44234481, e-mail : philippe.bonnifait@hds.utc.fr;
4. Thales Alenia Space France, Toulouse,
phone: +33 5 34353513, e-mail : philippe.poire@thalesaleniaspace.alcatel.fr
5. Navteq, Brussels, phone: +32 2 715 7094, e-mail: katia.demaseure@navteq.com

ABSTRACT

This paper describes the system approach for a future positioning system to be developed for the European CVIS project (www.cvisproject.org) that deals with an increased transport safety and efficiency using advanced positioning, mapping and communication technologies. Positioning and mapping functions will be provided by the sub-project POMA, where new methods for the combination of several positioning components will be developed. The whole positioning system setup of CVIS will then be deployed at DLR in Berlin. This setup will not only cover onboard components but also infrastructure based sensors and sensor networks together with enhanced positioning algorithms. This new approach shall enable high accuracy and reliability for the following field trials spread over Europe.

KEYWORDS

CVIS, POMA, vehicle positioning, vehicle-to-infrastructure (V2I) communication, dead-reckoning, GNSS augmentation, EGNOS, accuracy, integrity, IMU, WLAN

INTRODUCTION

Due to the increasing number of road congestions and high number of accidents and fatalities within the growing EU the European Commission decided to issue an eSafety call within the 6th framework program to develop "co-operative systems" for the enhancement of road safety and efficiency. CVIS (Co-operative Vehicle Infrastructure Systems) is one of three integrated projects funded within this call. It deals with the development and introduction of new systems and services through networking between vehicles and infrastructure and is managed by ERTICO ITS Europe (Brussels, www.ertico.com). The intended and field-tested future services are based on several new technologies for vehicle-to-infrastructure (V2I) communication as well as on advanced positioning and mapping systems, developed in several sub-projects (SP). POMA is one SP within CVIS and tries to provide among latest mapping modules also an advanced positioning system, that meets the requirements of the envisaged services. For that purpose, POMA has to propose a new approach with onboard plus infrastructure based components combined with high performance new positioning and map matching algorithms. It also includes open Application Programming Interfaces (API) and the provision of integrity indicators. This technical approach will be briefly described in this paper.

STATE-OF-THE-ART

Up to now the positioning of vehicles of any transport mode is primary done by onboard components, which can also include signals or supporting information by off-board elements - e.g. GPS satellites and augmentation systems for differential corrections. Due to limited performances even by this modern satellite system - originally expected to be the ultimate solution - more and more applications are meanwhile appearing with requirements not being met by GPS. As a consequence, many solutions are moving towards integrated systems that combine different and complementary sensors.

The widespread onboard navigation systems in vehicles are meanwhile based on wheel speed, inertial or magnetic sensors matched to digitised road maps. These systems use GPS for start-up and regular correction on absolute positions. GPS as a stand-alone system is not sufficient for an increasing number of transport applications due to limited visibility to the satellites within urban canyons, tunnels, mountains or buildings for instance. Even the latest space-based augmentation systems (SBAS) EGNOS, WAAS and others can in fact increase the final accuracy and supply integrity information, but only where these augmentation information will additionally be received.

Infrastructure based sensors are basically used for traffic management or law enforcement applications using stationary cameras, induction loops, beacons or other appliances. Those components can also be used for a precise and reliable positioning of vehicles. But there is up to now no solution for wide areas that combines all this information to one final application using networking and mobile communication technologies.

Cellular networks are in many countries just under consideration for user localisation. This technology is able to locate a mobile phone within a few hundred meters accuracy as far as it is in operation. It is well advanced in the U.S. due to legal measures by the government forcing the service providers and device manufacturers to enhance this technology step by step and implement a GPS receiver into all new mobile phones. The background is to enable an area-wide emergency (911) positioning capability so that every originator can be located. In Europe this technology is not yet as advanced as in the U.S. and is not able up to now to support a positioning service up to a sub-meter accuracy that would be needed for CVIS purposes.

But finally, geographical information and Geo Info System (GIS) systems can contribute themselves to the positioning process. They first can be used as constraints that characterise the location space where the vehicles can be located. This is typically the use of maps of the road network. Their second use concerns the management of any landmark or beacon in a unified framework.

REQUIREMENTS & IMPROVED FEATURES

Future telematics services as foreseen in CVIS/POMA will need more advanced technologies than available today. Not even a higher demand on the communication links between vehicles, infrastructure and service centres but also the localisation of vehicles (or even persons) have to be improved. When establishing chargeable services e.g. for road or parking area usage or law enforcements the technology has to guarantee a dedicated service level with a minimum of reliability, accuracy and integrity. Thus there are not only requirements coming from customer services to achieve the intended quality. There have also legal aspects to be considered to enable the deployment of several services based on positioning technologies. Therefore the final solution will have to achieve not only a dedicated accuracy in all areas (that means for instance less than one meter for lane separation even in tunnels) but has also to guarantee this accuracy and provide the integrity of the position information. This will be a special challenge of an advanced positioning system for future telematics systems and services.

SYSTEM ARCHITECTURE

Having learned the previous lesson, CVIS (POMA) is entering a new approach in developing an advanced positioning system concept for the mentioned purposes. The emerging new system will cover a multi-level solution. It combines new sensing technologies with advanced positioning algorithms. The sensing part of the system will be divided into two blocks (fig. 1):

- the vehicle (onboard) positioning system and
- the infrastructure based positioning system.

The infrastructure and onboard components will be wireless linked with each other via certain radio or IR-based communication channels such as Dedicated Short Range Communication, WLAN or cellular networks. The communication function will also consider future standards like CALM M5 or 4G. The task to establish communication features will be covered by the CVIS sub-project “COMM” and is not in the focus of POMA.

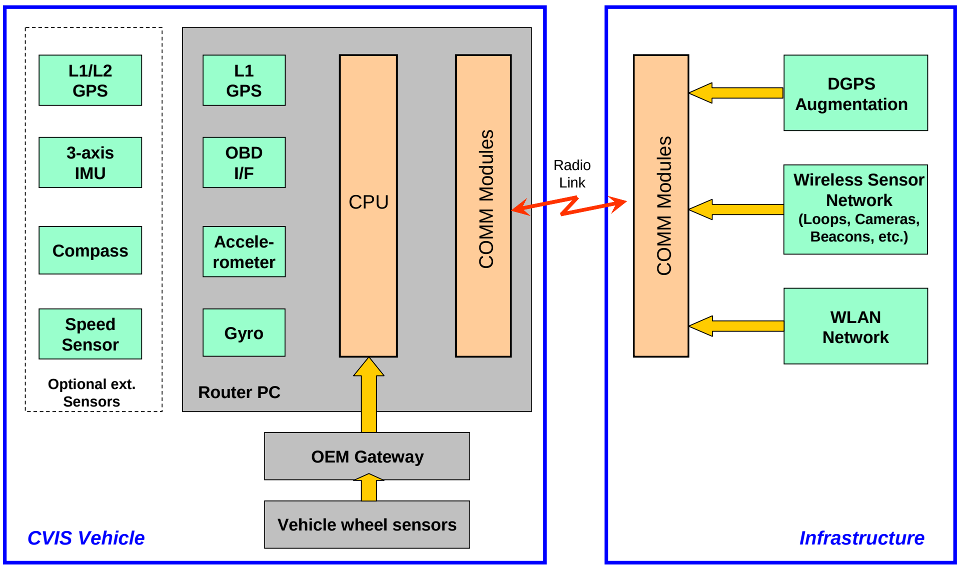

Figure 1 - Block diagram of the POMA positioning components

Onboard components

The basic function for the vehicle localisation is a combined dead-reckoning (DR) and satellite-(GNSS-) based positioning. Since both principles are complementary to each other a combination of both is meanwhile state-of-the-art in most car navigation systems. Even this system setup will also be the baseline for other e-Safety projects like SafeSpot for instance [1].

But for DR purposes the system needs the vehicle or better the wheel speed information and any kind of direction or turn-rate indication. Most of the car manufacturers (OEMs) meanwhile use internal data busses to transmit wheel speed, accelerometer, gyroscope and other safety related data internally to an onboard computer. But these data are in general not accessible by external devices that do not belong to the OEMs service or development equipment.

Since the sub-project POMA has to provide a reliable positioning service but has no influence on the car sensor data provided by all test vehicles, it has been decided to propose a two-level solution (figure 1):

I. The standard low-cost solution will include an own sensor module within the CVIS onboard computer that also contains the communication components. This sensor module comprises accelerometer and yaw-rate gyro in micro-electro-mechanical-system (MEMS) technology, a regular GPS/Galileo receiver module plus an interface-chip that supports the access to the standardized onboard diagnostic (OBD) interface of most cars. Thus POMA can supply its own inertial data and tries to use the vehicle speed data that will be provided via a separate OEM gateway. In the best case these data will contain speed or odometry information about all four wheels, typically needed for driving safety applications (e.g. ABS, ESP). If no data will be provided via this gateway, the sensor board can also connect to OBD interface of the vehicle to read at least the vehicle speed. This information will then be used for a DR calculation and a data fusion with the GPS position as a first simple but quite reliable position estimation.

II. If the used vehicles of certain applications or test sites do not supply POMA with dedicated vehicle localisation data or if a higher accuracy for the position result is required POMA can propose additional onboard sensors to be connected to the onboard computer. These sensors are:

   - a high performance GPS receiver with dual-frequency reception for Real time Kinematic (RTK) measurements and vehicle positioning with a sub-meter accuracy,
   - a high accurate 3-axis Inertial Measurement Unit (IMU) for increased inertial sensing,
   - a magnetometer as compass sensor i.e. absolute direction indicator for start-up or blackout phases and
   - a high accurate speed sensor to be mounted externally on the vehicle.

Infrastructure based components

To support the onboard sensing system externally, additional sensor setups will be provided to detect or even localise test vehicles at least at certain locations. Since the use of satellite signals and even the combination with DR sensors can not consider all application environ-ments, POMA needs additional information coming from the infrastructure side in certain situations. For that purpose two different but similar technologies will be introduced for CVIS:

a) WLAN positioning:
   When using regular wireless multimedia technologies along certain road strips, not only high speed communication features will be supported. The measurement of the reception signal at several WLAN access points (APs) will also enable an estimation of the position of a user by using a finger print approach [8].

b) Wireless sensor network:
   Using existing sensors for traffic management and detection purposes (e.g. induction loops, cameras, IR beacons, radar sensors) the detected vehicles can also be localised when passing a sensors location. Adding special short range radio transceiver to these sensors the whole sensor network can be cross-linked to each other and the individual locations can be determined through radio triangulation and mapped in a sensor table. The detected vehicles can than be allocated to these positions very reliably and accurately.

c) IR-beacons:
   For short range communication purposes, new IR-technologies will be introduced along certain road strips or intersections. These devices are also able to identify and localise passing vehicles and can even perform range measurement within their coverage area along dedicated lanes.

The infrastructure based positioning results will finally be transferred to the certain vehicle and will be fed to the positioning algorithm of the onboard computer to supplement in-vehicle sensors by independent external data sources. This can increase the reliability and accuracy of the final positioning result in particular where onboard sensing equipment fails even in difficult environments (tunnels, road canyons, etc.).

GNSS augmentation

The accuracy and integrity of GNSS positioning can be improved by using EGNOS data. EGNOS is an European system that generates correction data to compensate inaccuracies of the GPS system (clock errors, ionosphere, orbital corrections, etc.) [2]. The EGNOS correction data is broadcasted in streaming mode using 3 geostationary satellites and the Internet. However, these two broadcasting methods have several shortcomings: satellites are not always visible (almost never in cities) and the low data rate (250 bit/s) implies that the user must listen to the EGNOS data source for at least 15 minutes to have the complete EGNOS data base. The Internet broadcasting method uses the same data rate as the geo satellites.

In CVIS/POMA it is proposed to use a system that will sent the entire EGNOS database to the user at once, thanks to the bandwidth made available by the COMM subproject. Using this approach, the system will be able to compute an EGNOS-compliant position a few seconds after system start-up. An EGNOS server installed in a location with a clear line of sight to the EGNOS geo satellites will maintain an updated EGNOS database and send it upon request to any CVIS-equipped vehicle.

By computing the GNSS position using the EGNOS position, the accuracy will be improved to about 1 to 3 meters. Also, any GPS satellite failure will be detected by EGNOS and a “don’t use” message will be sent to the vehicle. Using the signal from a malfunctioning GPS satellite can lead to positioning error in excess of 1 km, therefore it is mandatory to exclude this satellite from the solution in order to guaranty the position integrity. Malfunction in GPS satellite are more and more frequent since many satellites are reaching the end of the expected life.

FUNCTIONAL ARCHITECTURE

The position, velocity & time (PVT) calculation will be executed in several steps. The first step is to calculate satellite based PVT with GNSS raw data and EGNOS information. This solution still depends on the conditions of reception of the satellite signals and can also lead to incorrect or invalid results. Thus not only the accuracy but also the integrity of this result has to be considered, where EGNOS information among others may be helpful.

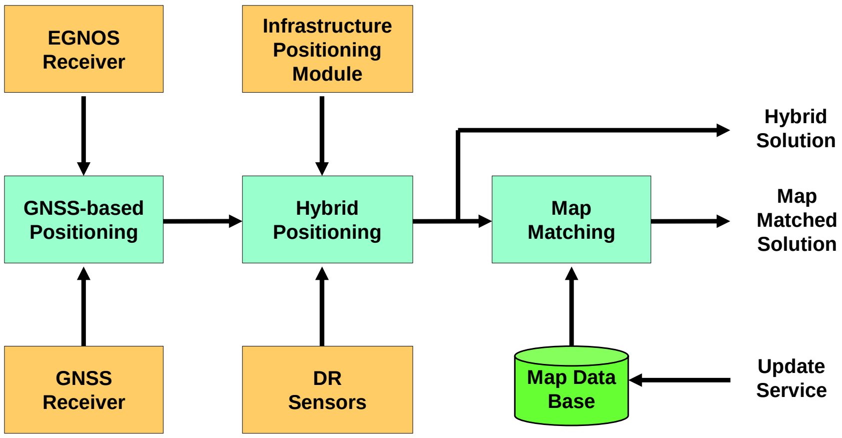

Figure 2 - Main functions of the position calculation process

The next step is to fuse these data with DR and infrastructure based sensor or position data by a high enhanced new algorithms (see next chapter). This module will combine the GNSS-, the DR- and the external position / detection data to a hybrid PVT solution with extended information about accuracy and integrity (confidence information).

Finally the PVT calculation can be enhanced by a map matching process that compares the calculated hybrid solution to an onboard digital map data base. This map data base will be updated by separate processes not regarded here in more detail. This map matched solution can even distinguish between lanes using particular attributes that have to be provided by the digital map.

ENHANCED POSITIONING ALGORITHM

POMA will develop new position algorithms fusing all these sensor data to maintain a location estimate during GPS outages and for integrity purposes.
Along with well-known Kalman filter, there will be introduced an Interactive Multiple Model algorithm [5], capable of optimising the choice of combined sensors and models (particularly models for the vehicle trajectory) versus different driving situations. Further, the positioning data fusion module will feed the road-matching module: This one will not only determine the most probable map data road, but also a set of next probable segment-matched locations, limited to ten, each given with its level of confidence ant its associated longitudinal inaccuracy [6]. Internally, the map-matching module contains a road cache memory (Region Of Interest - ROI) updated by a reliable mechanism that guarantees that the position always belongs to this selected area. Typically this mechanism depends on the speed and the latency

of the map engine. The size of the cache is optimised considering real-time and embedded constraints.

POMA positioning modules will compute integrity information. Positioning integrity [7] can be interpreted as the aptitude to detect then to eliminate aberrant measurements in order to estimate a positioning whose inaccuracy and confidence are quantified. Confidence can be defined as the probability associated with the localization assumption considered. Integrity is often represented by a confidence circle whose centre is the best estimation of the position. The confidence circle (protection zone) is an upper bound of the real error (difference between the real position and computed position). The confidence circle must also be minimised in size in order not to prevent the deployment of application in need for a good accuracy. The choice of the probabilities associated with False Alarm Rate and Misdetection of errors are the key issues. Integrity is complemented by an alarm flag used to alarm the whole system about a positioning system failure.

Additionally, even more advanced algorithms will fuse sensor data together with precise 3D map data. The main idea with precise 3D maps is to enrich the classical multi-segment description provided by map suppliers in areas of special interest (complex or dangerous areas) where using an ADAS is particularly relevant. A suitable model for this improvement could be something close to the CAD model used by road designers (straight lines, curves, clothoids, longitudinal and transversal profiles). The two main advantages of such a modelling are:

- It offers a continuous vector representation with an "infinite" resolution while the resolution of a multi-segment discrete representation is limited to a certain number of points. Map display and user system interface could take advantage of this modelling.

- Also, this modelling is well fitted to the computation of data fusion and map-matching algorithms, because it makes possible to include parametric equations in the filtering process.

A fully representation of the road typically enable modelling of the local tangent plane of the road as well as its two borders and central lane. POMA should choose to use a 3D equation of these plane and lane as constraint in positioning data fusion algorithms (using GPS, gyro and odometer). In this approach, the positioning and map-matching issues become a unique and common process. Moreover, in addition to the delivery of the set of probable segments, map-matching on enhanced maps could also give the probability of occupancy of each lane for each segment probable. Geometrical parameters, as well as the number of lanes, could be attached to nodes and segments, like other attributes in the existing road maps.

Last but not least inside the CVIS concept, POMA developers will also pay attention to the ability of the positioning subsystem to generate in return local dynamic map information to the map data base. Thus POMA will at first develop a new compilation of localisation solutions mixing traditional with advanced technologies for position sensing and processing including map data support. This system will finally be used as the basic positioning system for all applications covered by CVIS and can therefore become the first unified positioning platform for telematics applications in Europe.

TEST & VALIDATION

The test of the developed CVIS and POMA system will be performed in several steps: the Alpha-, Beta- and Gamma-tests including the respective prototypes and system setups. The Alpha-test setup will include a prototype platform for the whole positioning system of POMA and thus of CVIS. The Beta-test covers the integrated overall system not only for positioning, while the Gamma-test are the final tests at six European test sites for real application in urban, interurban and rural environments.

The Alpha-prototype includes onboard sensors, onboard computer and communication components installed in a test vehicle. Furthermore the infrastructure components will be considered as well including road sensor networks with cameras, induction loops, IR-sensors, WLAN access points and other radio communication systems to be deployed at a special experimentation road and connected to an operation centre.

Test vehicle and experimental road will built the POMA Alpha-test setup as an overall reference system. This reference system will be deployed at the premises of the German Aerospace Centre DLR in Berlin (Germany) using its “Experimentation Road” and “Traffic Tower”. The final concept will then become part of the overall CVIS platform and system to be deployed at seven Europe-wide test sites. The reference system in Berlin can also be used by other national or international projects (e.g. SafeSpot or COOPERS) dealing with cooperative systems, vehicle-to-infrastructure, advanced positioning or other telematics technologies.

EXPECTED RESULTS

The output of POMA to CVIS applications will not only be the position, speed or segment ID of vehicles but will also include an information about the accuracy of the data in the shape of a ‘confidence ellipse’ around each vehicle, as well as an indicator of the reliability of this information for purpose of integrity.

Figure 3 - Experimentation road at DLR Berlin for the system tests

The application sub-projects of CVIS performed at the six test sites cover several exemplary demonstrations in urban and interurban environments as well as for fleet and freight transport. POMA has a unique opportunity for the introduction and optimisation of its technology through the joint European research project CVIS. Hence, the developed CVIS technologies, where the POMA positioning system belongs to, will be introduced to many relevant ITS applications and can pave the way towards future telematics standards. Many European vehicle manufacturers, suppliers and research organisations will contribute to the final solution that will also be harmonised with other national and international activities, projects and standard.

The first step for the realisation of this future co-operative positioning system is to deploy the mentioned Alpha test setup according to the described architecture and design and to perform all tests relevant for any kind of urban or interurban applications. These tests shall ensure a proper functioning of the system as a reference for a further Europe wide implementation.

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