Published in IET Intelligent Transport Systems
Special Issue-selected papers from ITS '07
Received on 11th September 2007
Revised on 13th February 2008
doi: 10.1049/iet-its:20070046

ISSN 1751-956X

Advanced positioning technologies for co-operative systems

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Abstract: The authors describe a systems approach for a future positioning system to be developed for the European co-operative vehicle infrastructure systems (CVIS) project that deals with increased transport safety and efficiency using advanced positioning, mapping and communication technologies. Positioning and mapping functions will be provided by the sub-project for positioning, mapping and location referencing (POMA), in which 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. Furthermore, new functionalities for mapping and map matching as well as the consideration of integrity conditions and confidence circles are a major topic of the work. This new approach will ensure high accuracy and reliability of field trials spread over Europe.

1 Introduction

Owing to the increasing road congestion and the large number of accidents and fatalities within the growing EU, the European Commission decided to issue an eSafety call within the sixth framework programme to develop 'co-operative systems' to enhance road safety and efficiency. Co-operative vehicle infrastructure systems (CVIS) is one of the three integrated projects funded within this call [1]. 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 [2]. These services, intended to be used and field-tested in future, 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 (positioning, mapping and location referencing) is one SP within CVIS and tries to provide, among the latest mapping modules, an advanced positioning system that meets the requirements of the envisaged services. For this purpose, POMA has to propose a new approach with onboard plus infrastructure-based components combined with new high performance positioning and map-matching algorithms. It also includes open application programming interfaces and the provision of integrity indicators. This technical approach will be described in this paper.

The paper is organised as follows: recall of the state-of-the-art and CVIS requirements, presentation of the information technology used – from the sensor instrumentation onboard and on the roadside to enhanced digital maps – and overview of POMA development and experiments.

2 State of the art

Up to now, the positioning of vehicles of any transport mode is primarily done by onboard components, which can also include signals or supporting information by off-board elements – for example, global positioning system (GPS) satellites and augmentation systems for differential corrections. Because of limitations in performance (from several metres for standalone GPS to sub-metre accuracy for differential GPS (DGPS) in terms of visibility of satellites, conditions of reception and signal-to-noise ratio, particularly in cities) even in this modern satellite system – originally expected to be the ultimate solution – the requirements of more and more applications are 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 currently based on wheel speed tracked by 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 because of the limited visibility available to the satellites, for instance, within urban canyons, tunnels, mountains or buildings. The latest space-based augmentation systems, EGNOS, WAAS and others, can in fact increase the final accuracy (to sub-metre order of magnitude) and supply integrity information (which, for instance, makes it possible to adopt 'use' or 'don't use' navigation solutions in applications like landing), but only where such augmentation information will additionally be received.

Cellular networks in many countries are now under consideration for locating users. This technology is able to accurately locate a mobile phone within a few hundred metres so long as the phone is in operation. It is well advanced in the U.S. because of legal measures by the government forcing service providers and device manufacturers to enhance this technology step by step and implement a GPS receiver into all new mobile phones. These legal measures were enforcedto 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 currently able to support a positioning service up to the sub-metre accuracy that would be needed for CVIS purposes.

Wireless networks using 802.11x protocols are also very interesting technologies for positioning purposes. Many scientific publications [3–5] have recently shown interesting results in the field of wireless sensor network (WSN) communication. By using many redundant communicating sensors, rough time-of-flight measurements can be merged together to provide local positioning information. An alternative consists in using detailed signal maps built in at the learning stage. By correlating its current observed signal intensities, the mobile receiver can determine its location [6].

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

Finally, geographical information and geo-information systems can contribute to the positioning process. First, they can be used as constraints that characterise the space where the vehicles can be located. This is typically the use of road network maps. Their second use concerns the management of any landmark or beacon in a unified framework.

3 Key features for cooperative systems

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), has to be improved. When establishing chargeable services, for example, for road or parking area usage or law enforcement, the technology has to guarantee a dedicated service level with a minimum of reliability, accuracy and integrity. Thus, requirements also arise from customer services to achieve the intended quality.

There are 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 but has also to guarantee this accuracy and provide the integrity of the position information. In CVIS, several applications have been defined and dealt with in certain SP. Position accuracy requirements depend on these applications. Thus, POMA defined three accuracy levels that can be requested by an SP application:

- 10 m level globally for 95% of urban and interurban areas;
- 1 m level globally for certain urban areas and
- sub-metre level (lane level) locally for dedicated crossroads, bus lanes or intersections.

All these items will be a special challenge for advanced positioning systems in future telematics systems and services.

In addition to this accuracy issue, POMA is intended to combine different kinds of sensor data. Several types of information that have originally not been considered for this purpose can be used for position indication and, finally, for localisation. Other technologies are highly advanced and accurate but can fail in certain situations or environments. Putting together all available information from onboard and off-board systems is quite a difficult task if the final result maintains constant accuracy and reliability. Thus, the required performances cannot be guaranteed in any case and the positioning system has to be able to autonomously qualify its outputs. Thanks to this metadata, the client applications will be able to check if the precision and the quality of the positioning information are high enough for their tasks.

Positioning integrity [7] can be interpreted as the aptitude to detect and 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 localisation 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 ideally the upper bound of the real current error (the difference between the real position and the computed position). In practice, the real error is unknown and the positioning system is only able to calculate the protection zone. The system is said to have integrity or be safe if its estimated error is larger than the real error. In order to avoid having too pessimistic a positioning, the confidence circle must also be minimised in size. In such cases, client applications of the positioning module specify thresholds above which the positioning data are declared unavailable. Therefore there is a compromise between accuracy and availability for a given system. The choice of the probabilities associated with false alarm rate and misdetection of errors are the key issues here. Often, an integrity check is complemented by an alarm flag used to warn the whole system about a positioning system failure.

For simplification purposes, the ‘circle’ assumption is often used, which facilitates the use of this confidence indicator for applications, since only a simple threshold can be used to declare an estimated location confident or not. When EGNOS is used, all faults are detected and removed from the computation. In this case, the radius of the circle typically corresponds to 6 times the estimated standard deviation of the major axis of the ellipsoid. If only RAIM is done, this radius is increased to take into account the possibility that an undetected fault has passed all the checks. This augmentation value is computed under the hypothesis that there is only one fault affecting the most sensitive satellite.

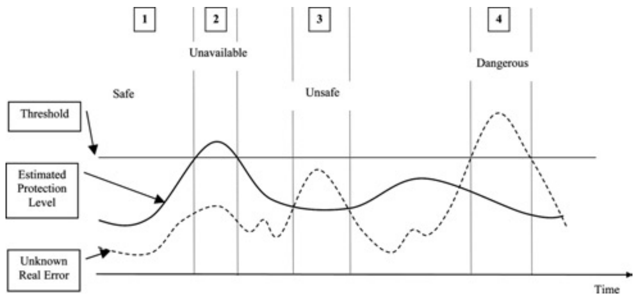

Figure 1 *Integrity scenarios for a positioning system*

In Fig. 1, several scenarios are presented. In area 1, the system is safe and available. In area 2, the protection level is too pessimistic, which leads to unavailability of positioning information. In area 3, the real error exceeds the protection level without any danger. In area 4, the use of the positioning information is dangerous: for instance, because the system has not detected a failure.

Fig. 2 illustrates the output of a safe system. Unfortunately, in the scenario presented, the threshold is low with respect to the protection level. The availability is poor here.

In cooperative systems, integrity levels depend on the applications. For traffic monitoring and navigation, low levels are acceptable. In these cases,availability is the more important issue. In contrast, there are applications that require high integrity (ghost driver detection, for instance) and others that additionally need high precision (bus lane allocation, for instance).

4 Technologies considered

Having learned many lessons from these issues, CVIS/POMA is entering a new phase in the development of an advanced positioning system concept for the abovementioned purposes. The emerging new system will cover a multi-level solution. It combines new

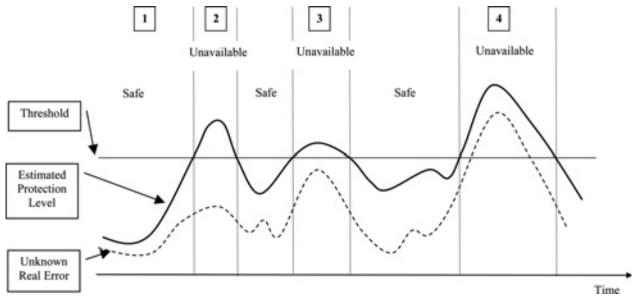

Figure 2 *High integrity system has a protection level correctly estimated*

sensing technologies with advanced positioning algorithms. The sensing part of the system will be divided into two blocks (Fig. 3).

- An in-vehicle (onboard) positioning system.
- An infrastructure-based positioning system.

The infrastructure and onboard components will be wireless linked with each other via radio or IR-based communication channels such as dedicated short-range communication, wireless local area network (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 SP 'COMM' and is not in the focus of POMA.

4.1 Onboard components

The basic function for the vehicle onboard localisation is a combined dead-reckoning (DR) and satellite-based (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. This system setup will even be the baseline for other eSafety projects like SafeSpot, [8, 9]. The onboard sensor setup includes the following types of sensors that will be connected to an onboard computer (OBC, that is called 'router PC' within CVIS, since the communication devices are included as well).

- GNSS receiver (still realised by a commercial GPS receiver).
- Inertial sensors (two-axis accelerometer plus one-axis yaw-rate gyroscope).
- Magnetic compass sensor.
- Vehicle speed and odometry inputs.

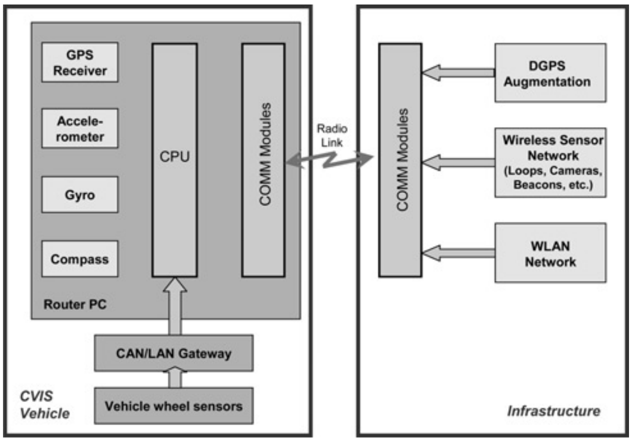

Figure 3 *Block diagram of the POMA positioning components*

For DR purposes, the system needs the vehicle speed, or better the wheels odometry information (elementary travelled distance), and any kind of direction or turn-rate indication. In the meantime, most of the car manufacturers (OEMs) use internal data buses to transmit wheel speed, acceleration, tilt and other safety-related data internally to an OBC. Unfortunately, these data are in general not accessible by external devices that do not belong to the Original Equipement Manufacturer service or development equipment, not because it is not technically feasible, but because of the OEMs policy/strategies in this matter. So a unified access to vehicle or wheel speed information is indeed one of the most challenging tasks within CVIS and similar projects.

Since the SP POMA has to provide a reliable positioning service and has no influence on the car sensor data provided by all test vehicles, it has been decided to propose the solution (Fig. 3) with several speed data sources. This low-cost solution will include an own sensor module within the CVIS OBC 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 access to the standardised onboard diagnostic (OBD) interface of most cars. Thus, POMA can supply its own inertial data and tries, in addition, to use the vehicle speed or even other data that will be provided via a separate CAN/LAN gateway. In the best case, these data will contain speed or odometry information about all four wheels plus inertial measured motion information, typically needed for driving safety applications (e.g. ABS, ESP).

If no data are provided via this gateway, the sensor board can also be connected to the OBD interface of the vehicle to read at least the vehicle speed with a client–server mechanism. This information will then be used for DR calculation and data fusion with the GPS position as a first, simple but quite reliable, position estimation. If the vehicles used in certain applications or at 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 external (but expensive) onboard sensors to be temporarily connected to the OBC for test purposes.

4.2 Infrastructure-based components

Since the use of satellite signals and even the combination with DR sensors cannot consider all application environments, POMA needs additional information coming from the infrastructure side in certain situations. As we consider communicating vehicles, particular attention has to be paid to wireless communication technologies for positioning purposes. An infrastructure-based localisation system is a set of devices that are attached to the infrastructure. There are two cases.

- The mobiles measure RF signal information coming from communication beacons.

- The mobiles are detected and localised using infrastructure-fixed devices.

Let us consider these two technologies in the following.

4.2.1 WLAN on-board 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 [10].

For short-range V2I communication, new WLAN technologies have been standardised. These technologies can not only be used for communication but also for positioning purposes so long as a minimum number of APs can be received at certain locations. Since such APs are meanwhile in widespread use and CVIS also uses these systems, it is useful to use the existing APs for signal strength measurements in an equipped vehicle. If these signal strengths at different locations are well known and stored in a database, then the measured values can be compared with these data to estimate the position of the vehicle. This implies that the signals have previously been measured area-wide within the radio coverage of the APs and these values are stored in the so-called ‘finger-print database’. If a CVIS-equipped vehicle enters such a known zone of APs (e.g. an intersection) and sends the measured signal strength values to a roadside server, the server can estimate the current position of the vehicle and return this result to the vehicle (see Fig. 4 for illustration).

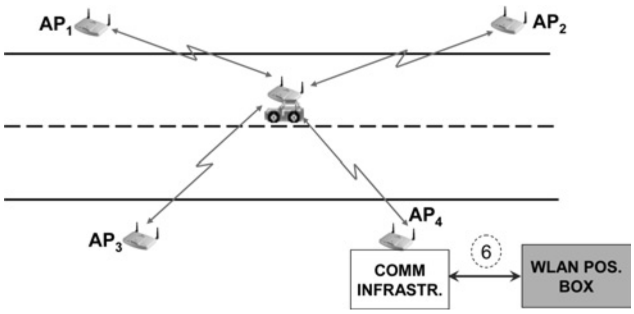

Figure 4 *Principle of the WLAN-based positioning*

4.2.2 WSN for localisation from the road side: To support the onboard sensing system externally, existing roadside sensors for traffic management, such as inductive dual loops, Doppler radars, video cameras, laser detectors, ultrasound radars and infrared/laser scanners can be used to localise vehicles, at least at certain locations. 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 then be allocated to these positions very reliably and accurately. A precondition here is to store as well the mapping of sensors and location information in a database. The localisation of the sensors can be done with the radio transceivers that are similar to WLAN modules, but can operate independently from a computer. These modules are semi-intelligent and can contact and exchange information automatically. Only one device will be used as a gateway to a connected computer as a link to the whole WSN server with the database.

The infrastructure-based positioning results will finally be transferred to the equipped vehicles and will be fed to the positioning algorithms of the OBC to enhance in-vehicle sensors by independent external data sources. This can significantly increase the availability, reliability and accuracy of the final positioning result, in particular where onboard sensing equipment fail because of difficult environments (tunnels, road canyons etc.).

4.3 GNSS augmentation

Accuracy and integrity of Global Navigation Satellite System (GNSS) positioning can be improved by using EGNOS data. EGNOS is a European system that generates correction data to compensate for inaccuracies of the GPS system (clock errors, ionosphere, orbital corrections etc.) [11]. The EGNOS correction data are broadcasted in streaming mode using three 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 min to obtain the complete EGNOS database. The Internet broadcasting method uses the same data rate as the geo satellites.

In CVIS, POMA proposes to use a system that will send the entire EGNOS database to the user at once, thanks to the bandwidth made available by the COMM SP. 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 1–3 m. 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 guarantee position integrity. Malfunctions in GPS satellites are more and more frequent since many satellites are reaching the end of their expected life.

4.4 Standard and enhanced digital maps

Maps of the road network can contribute to the positioning process. They can be used as constraints that characterise the location space where vehicles can be located. A key point is the representation of the road network stored in the database.

Nowadays, roads are often represented by polylines (nodes and shape points) that describe the geometry of the centre line of the roads. This is the representation used currently for navigation systems. In this case (Fig. 5), the outputs of the map-matching process are the segment identification number (ID) and the relative position of the vehicle along this segment, that is, the curvilinear abscissa (designated by *s*) from the node starting the segment (origin node).

For some specific applications, in some specific areas or spots, the road geometry needs to be described in detail. In particular, the road model must define the lanes, which can be numerous and rapidly changing in some critical urban highways. For example, in Cooperative Traveller Assistance, the user would appreciate guidance at the lane level – for enhanced driver awareness purposes, some warnings can be much more relevant if they are addressed depending on the lane the user in driving on; for a flexible bus lane allocation, it is absolutely mandatory to model the bus lanes. The idea consists of improving map precision and information content in terms of not only longitudinal but also lateral connectivity. Using these maps and their attributes of connectivity, seems to be a new concept for GPS-DR and map-matching purpose. Some authors [12–14] designed map-aided localisation, but they never precisely modelled the road, including lanes and a two-dimensional (2D) connectivity framework.

This detailed model at the lane level is to be used with a localisation and a map-matching process, which is, of course, compatible with yielding at the end a map-matched position of the vehicle at the lane level (Fig. 6). In this respect, if the road geometry is accurate and can be completed with accuracy indicators, it can be used as a constraint to enhance the positioning. A unique positioning/map-matching algorithm could be more efficient that a two-step process: positioning plus map matching. Indeed, thanks to this approach the map can be used to bind (within the road width) the drift of a DR estimate, which can be useful when GPS is not available for a long time, as for instance, in urban canyons. In the case of advanced 2D map matching, the output of the map-matching process is the segment ID, the relative position of the vehicle along this segment and the relative transversal position of the vehicle with respect to one of the border lines considered as the reference line. First results obtained with real measurements with only two lanes are encouraging and should be generalised to larger emap (enhanced map) areas.

In some cases, in particular in interchange areas with exit and entry lanes, the map-matching process can be disturbed by the presence of several roads at different levels at the same place. Moreover, advanced positioning/map-matching processes [15] merge the raw GNSS observables (pseudo-ranges) with the map information and the altitude of the road if available. Locally, this road can be considered as a plane, which gives one equation more in the satellites-positioning problem.

To sum up these ideas, we wish to address the issue of adding to the standard map content, for some specific areas, a detailed and accurate (<1 m) 3D model of the road (with attributes that may potentially differ depending on the lane) that can be used for advanced map-matching at the lane level. This detailed local static map should be added using the normal POMA update process.

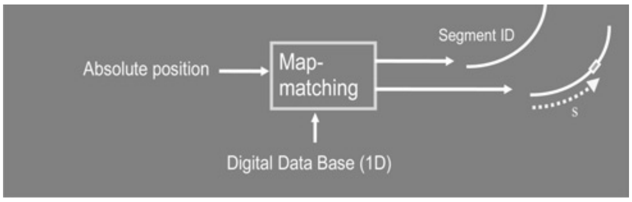

Figure 5 *Usual map matching*

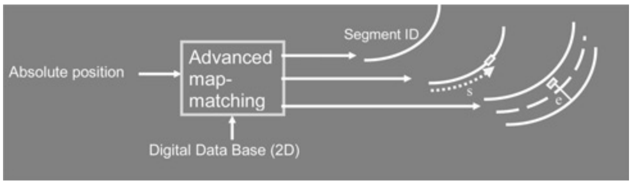

Figure 6 *Advanced 2D map matching*

5 Information processing proposed approach

POMA will develop new position algorithms fusing all sensor data already presented in Section 4, in order to maintain a location estimate during GPS outages and for integrity purposes. The next sections will present the two main directions of the algorithmic research carried out within the framework of POMA in the CVIS project. To summarise, the first direction aims at fusing GNSS and DR but also external position data from the wireless network, whereas the second, based on a new precise map (whose processing is described hereafter), will achieve fusion and map-matching in a unique tightly coupled process. Integrity and confidence information should also be computed by these algorithms.

5.1 *Information processing architecture*

The position, velocity and time (PVT) calculation will be executed in several steps, as illustrated in Fig. 7.

The first step is to calculate satellite-based PVT with GNSS L1 raw data and EGNOS information. This solution still depends on the conditions of reception of 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. Thanks to the bandwidth made available by the COMM SP, the GNSS-based positioning module is able to compute an EGNOS-compliant position a few seconds after system start-up, by using an EGNOS server installed in Toulouse, France. This server maintains an updated EGNOS database and sends it upon request to any CVIS-equipped vehicle. A second external dual-frequency GNSS receiver can also be used by this module for very dedicated applications needing real-time kinematic accuracy, or for validation purposes (to the extent that kinematic GPS, coupled with an external Inertial Measurement Unit (IMU), can make a reference trajectory [16]).

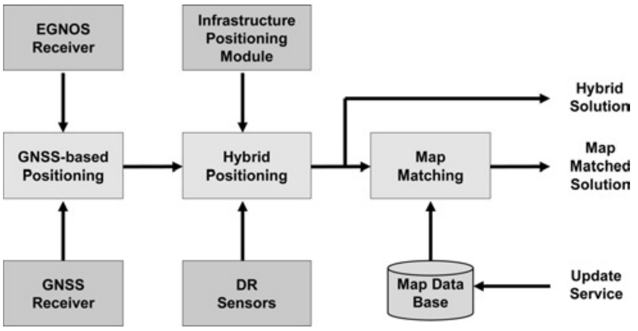

Figure 7 *Main functions of the position calculation process*

The next step is to fuse these data with DR and infrastructure-based position data by an enhanced new algorithm. This module will combine the GNSS, the DR and the external position data to a hybrid PVT solution with extended information about accuracy and integrity. Along with the well-known Kalman filter [17], an interactive multiple model algorithm [18], capable of optimising the choice of combined sensors and models (particularly models for the vehicle trajectory), will be tested in different driving situations. This approach in particular, should provide the best compromise prediction of vehicle behaviour, for example, among keeping its velocity, or deviating from its current heading, or again accelerating/decelerating.

Finally, the PVT calculation can be further processed by map-matching. This module will compare the calculated hybrid solution to an onboard digital map database; it will not only determine the most probable map data road element, but also a set of next probable segment-matched locations, limited to 10, each given with its level of confidence and its associated longitudinal inaccuracy [19]. Internally, the map-matching module contains a road cache memory (region of interest) 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 [20].

5.2 *Enhanced map representation*

We are studying how to collect, model and use precise 3D maps to enrich the classical multi-segment description provided by map suppliers in areas of special interest (complex or dangerous areas), where using an advanced driver assistance system (ADAS) is particularly relevant. A suitable model for this improvement could be something close to the computer-aided design (CAD) model used by road designers (straight lines, curves, clothoids and longitudinal and transversal profiles). A complete representation of the road typically enables modelling of the local tangent plane of the road as well as its two borders and the central lane. Such maps exist, of course, particularly for new roads, where CAD was used, and its use in construction was fundamental to the concept of site robotics or computer-integrated road construction [21]. 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.

doi: 10.1049/iet-its:20070046

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

There exist several data collection methods that could be used to constitute these 3D detailed maps, among which mobile mapping appears to be of great interest. A literature survey made in the frame of POMA Emap showed several algorithms for achieving the critical step of geometric identification based on vehicle trajectory. Most are based on least square linear and nonlinear regressions for, respectively, straight lines and circles. An algorithm suitable for the identification of clothoids has not been found, those being generally determined afterwards between lines and circles formerly obtained. Tuning of the algorithms that we tested was always difficult, mainly because of their high sensitivity in computing a radius of curvature with noisy positions. Moreover, relatively large errors exist around the extremities of lines and circles, that is, at transitions where clothoids need to be computed: these clothoids therefore are generally offset with respect to the real geometry.

We designed a new algorithm based on an extended Kalman filter (EKF). It processes the parameters of only clothoids (and not of lines or circles), using positions as observables. Parameters are set in the state vector, assuming constant evolution law. A unique threshold needs to be tuned: this is the level of error above which a position is considered as aberrant with respect to the current set of clothoid parameters. If a series of three consecutive solutions exceed this threshold, a new clothoid starts (three positions make the computation of a clothoid possible). Fig. 8 illustrates, on a mobile mapping data set near the German Aerospace Centre DLR in Berlin (Germany), both the computation of clothoids and longitudinal and lateral connectivity. This area typically shows complex features, where an ADAS capable of lane separation could be of great use.

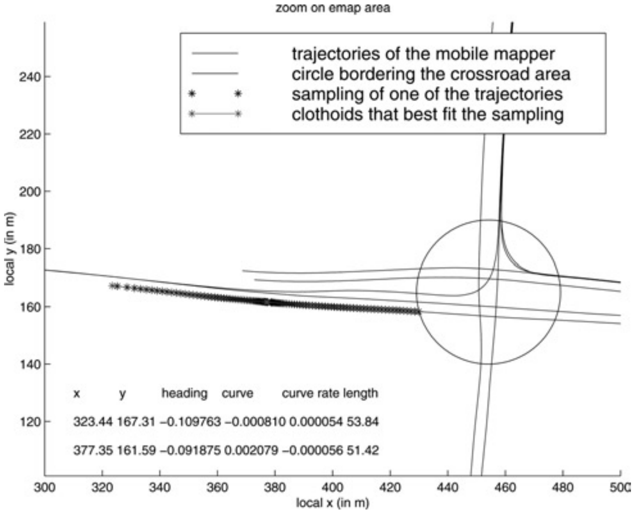

Figure 8 *Emap computation: zoom on a crossroad near DLR Berlin*

Every possible lane has been noted. A van was instrumented for that purpose, with the following sensors.

- GPS antenna and receiver capable of L1/L2 phase data 5 Hz logging for post-processing kinematic positioning (note that this receiver also provides its pulse-per-second synchronisation signal (PPS) to the acquisition PC on-board).
- fibre optic gyrometer, vertical only, at 10 Hz.
- Wheel or gearbox odometer.

Fusion of these measurements is processed in a first step, with forward EKF and backward rough smoothing. This gives solutions regularly sampled in space or time, whether GPS was masked or not. Afterwards, clothoids that best fit can be identified in a second step.

In addition, POMA will study the quality control procedures necessary to assess and classify the quality level of the map resulting from the existing mapping methods.

Hence, a road model based on an analytical description of the elements (lines, circles, clothoids, parabolas etc.) and properly characterised in term of precision, would be much more interesting than polylines, first for content size and second for positioning/map-matching process reasons.

5.3 Tightly coupled fusion and map matching

In parallel with the architecture described in Fig. 7, we are studying advanced methods for the fusion of raw sensor data (GNSS pseudo-ranges, ephemerid data and EGNOS corrections) together with precise 3D map data.

The problem of map-matching is usually tackled using GNSS fixes provided by a receiver, that is, position solutions computed using pseudo-ranges, ephemerid data and DR measurements. The main drawback of this approach is the necessity for at least four satellites in line of sight, conditions that are rarely satisfied in urban canyons. Moreover, integrity monitoring is difficult to assess in such cases, as the pseudo-range measurements can suffer from multipath. An alternative is a tightly coupled approach in which the map information is used in the computation of the fix. This approach also allows the mixing of GPS, Glonass or Galileo pseudo-ranges and multi-path mitigation.

We are studying the use of 3D equations of the precise planes and lanes as constraints in positioning data fusion algorithms. 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 probable segment. Geometrical parameters, as well as the number of lanes, could be attached to nodes and segments, like other attributes in the existing road maps. The work presented in [15] has successfully fused L1-GNSS pseudo-ranges with usual maps. A particle filter by nature capable of tracking multiple probable segments has also been identified as a rather relevant solution, worth being investigated.

6 Prototyping and validation issues

The tests of the developed CVIS and POMA system will be performed in several steps: 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, and not only for positioning, while the gamma-tests are the final tests at six European test sites for real applications in urban, interurban and rural environments.

The alpha-prototype includes onboard sensors, OBC 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 APs and other radio communication systems to be deployed at a special experimentation road and connected to an operation centre.

Figure 9 *Experimentation road at DLR Berlin for the system tests*

Test vehicle and experimental roads will build the POMA alpha-test setup as an overall reference system. This reference system will be deployed at the premises of DLR Berlin using its 'Experimentation Road' and 'Traffic Tower' (Fig. 9). 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 co-operative systems, vehicle-to-infrastructure communication (V2I) advanced positioning or other telematics technologies.

The ^{RT}Maps software (real-time multisensors advanced prototyping software) from Intempora has been chosen to perform data acquisition by the sensors and to integrate the real-time software modules from the different partners. It also allows synchronised data recordings and playback from the different sensors, which is helpful for the development phase.

As shown in Fig. 10, data from multiple sensors such as GPS, compass, IMUs, inclinometers, CAN bus etc. will be used. Positions computed by fusing low-cost sensor data will be validated with the help of other more expensive sensors such as an L1/L2 DGPS and leading-edge inertial sensors. In order to ensure correct synchronisation of the different onboard and infrastructure-based systems, the ^{RT}Maps timebase will be bound to the UTC time provided by the GPS sensor and its PPS signal.

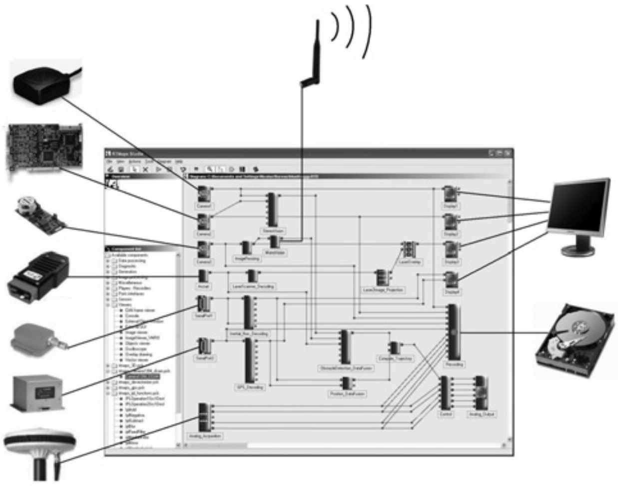

Figure 10 *Sensors acquisition, processing and recording under RTMaps*

doi: 10.1049/iet-its:20070046

Preliminary experiments have been carried out for POMA alpha-test and are still in the process of extensive analysis.

7 Conclusion

The output of POMA to CVIS applications will not only be the position, speed or segment ID of vehicles but will also include 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 the purpose of integrity.

The application SP 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 the unique opportunity to introduce and optimise its technology through the joint European research project, CVIS. Hence, the developed CVIS technologies, to which the POMA positioning system belongs, 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 standards.

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 will ensure a proper functioning of the system as a reference for a further Europe-wide implementation.

Last but not the least, within the CVIS concept, POMA developers will also pay attention to the ability of the positioning sub-system to generate in return local dynamic map information to the map database. 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.

8 Acknowledgments

The authors would like to thank Philippe Poiré (from Thales Alenia Space), Nicolas Dulac (from Intempora – ^{RT}Maps) and Francesco Sottile (from ISMB, Turin) for their precious collaboration.

A previous version of this paper was presented at the ITS '07 European Congress held in Aalborg, Denmark in June 2007.

9 References

[1] See the official website www.cvisproject.org

[2] See the official website www.ertico.com

[3] COSTA J.A., PATWARI N., HERO A.O. III: 'Achieving high-accuracy distributed localization in sensor networks'. Proc. Int. Conf. Acoustics, Speech and Signal Processing, March 2005, vol. 3, pp. iii/641–iii/644

[4] PATWARI N., HERO A.O., PERKINS M., CORREAL N.S., O'DEA R.J.: 'Relative location estimation in wireless sensor networks', *IEEE Trans. Signal Process.*, 2003, **51**, (8), pp. 2137–2148

[5] SAVARESE C., RABAEY J.: 'Robust positioning algorithms for distributed ad-hoc wireless sensor networks'. Proc. General Track: 2002, USENIX Annual Technical Conf., 2002, pp. 317–327

[6] HAEBERLEN A., FLANNERY E., LADD A.M., RUDYS A., WALLACH D.S., KAVRAKI L.E.: 'Practical robust localization over large-scale 802.11 wireless networks'. Int. Conf. Mobile Computing and Networking, Philadelphia, PA, USA, 2004, pp. 70–84

[7] BAKHACHE B., NIKIFOROV I.: 'Reliable detection of faults in measurement systems', *Int. J. Adapt. Control Signal Process.*, 2000, **14**, (7), pp. 683–700

[8] See the official website www.safespot-eu.org/

[9] SCHUBERT R., SCHLINGELHOF M., CRAMER H., WANIELIK G.: 'Accurate positioning for vehicular safety applications – the SAFESPOT approach'. 2007 IEEE Spring Vehicular Technology Conf., Dublin, 2007

[10] BAHL P., PADMANABHAN V.N.: 'RADAR: An in building RF-based user location and tracking system'. Proc. IEEE Infocom 00, April 2000

[11] VENTURA-TRAVESET J., FLAMENT D, *ET AL.*: 'EGNOS – The European Geostationary Navigation Overlay System – a Cornerstone of Galileo' (ESA Publications, 2007), Reference ESA SP-1303

[12] LEE K.W., WIJESOMA S., IBANEZ GUZMAN J.: 'A constrained SLAM approach to robust and accurate localisation of autonomous ground vehicles', *Robot. Auton. Syst.*, 2007, **55**, pp. 527–540

[13] CUI Y.J., GE S.S.: 'Autonomous vehicle positioning with GPS in Urban Canyon environments', *IEEE Trans. Robot. Autom.*, 2002, **19**, p. 1

doi: 10.1049/iet-its:20070046

[14] SCOTT C.A.: 'Improved GPS positioning for motor vehicles through map-matching'. ION-94, Salt Lake City

[15] FOUQUE C., BONNIFAIT PH.: 'Vehicle localization in urban canyons using geo-reference data and few GNSS-satellites'. IAV 2007 6th IFAC Symp. Intelligent Autonomous Vehicles, Toulouse, 3–5 September 2007

[16] BÉTAILLE D., CHAPELON A., LUSETTI B., KAIS M., MILLESCAMPS D.: 'High integrity reference trajectory for benchmarking land navigation data fusion methods'. IEEE IV (Intelligent Vehicles) Annual Meeting, Istanbul, 7 June

[17] BÉTAILLE D., KAIS M., BONNIFAIT P., PEYRET F.: 'Development of loosely-coupled FOG/DGPS and FOG/RTK systems for ADAS and a methodology to assess their real-time performance'. IEEE IV (Intelligent Vehicles) Annual Meeting, Las Vegas, NE, 5 June

[18] HENK A.P.B., YAAKOV B.-S.: 'The interacting multiple model algorithm for systems with Markovian switching coefficients', *IEEE Trans. Autom. Control*, 1988, **AC-33**, (8), pp. 780–783

[19] EL NAJJAR M.E., BONNIFAIT PH.: 'Road selection using multi-criteria fusion for the road-matching problem', *IEEE Trans. Intell. Veh.*, 2007, **8**, (2), pp. 279–291

[20] BONNIFAIT PH., JABBOUR M., DHERBOMEZ G.: 'Real-time implementation of a GIS-based localization system for intelligent vehicles', *EURASIP J. Embedded Syst.*, 2007, **2007**, p. 12

[21] PEYRET F., JURASZ J., CARREL A., ZEKRI E., GORHAM B.: 'The computer integrated road construction project', *Int. J. Autom. Constr.*, 2000, **9**, pp. 447–461

doi: 10.1049/iet-its:20070046