

# HIGH ACCURATE POSITIONING FOR AUTONOMOUS VEHICLES ENABLED BY CONNECTIVITY

Author (1) Jessica García Soriano  
FICOSA; Viladecavalls, Barcelona, Spain; jessica.garcia@ficoso.com  
Author (2) Jordi Contreras Suñé  
FICOSA; Viladecavalls, Barcelona, Spain; jordi.contreras@ficoso.com  
Author (3) Maria Teresa Fernández Calzón  
GMV; Madrid, Spain; mtfernandez@gmv.com  
Author (4) Enrique Domínguez Tijero  
GMV; Madrid, Spain; edominguez@gmv.com  
Author (5) Javier Ibáñez-Guzmán  
Renault S.A.S.; Boulogne-Billancourt, France; javier.ibanez-guzman@renault.com  
Author (6) Emmanuel Stawiarski  
Renault S.A.S.; Boulogne-Billancourt, France; emmanuel.stawiarski@renault.com  
Author (7) Giuseppe Avellone  
STMicroelectronics; Catania, Italy; giuseppe.avellone@st.com  
Author (8) Philippe Xu  
Université de Technologie de Compiègne; Compiègne, France; philippe.xu@hds.utc.fr  
Author (9) Emanuela Falletti  
LINKS Foundation; Turin, Italy; emanuela.falletti@linksfoundation.com  
Author (10) Miguel Ortiz  
IFSTTAR; Bouguenais Cedex, France; miguel.ortiz@ifsttar.fr

## Abstract

The deployment of autonomous vehicles in our roads within the next future requires high accurate positioning information. It allows for vehicles to navigate in the correct lanes, position themselves correctly so to be able to affect future manoeuvres. For this purpose, several solutions have been developed to estimate the absolute and relative position of these in real-time. The only source available to estimate their absolute position is through the use of Global Navigation Satellite Systems (GNSS).

To place vehicle positioning within the stringent requirements that autonomous driving demands, much effort has been made in recent years to bring to the automotive sector the advanced error correction techniques applied in other domains like aviation. These include error correction in the position computed by a GNSS receiver using PPP algorithms (Precise Point Positioning). As PPP signals can be broadcasted widely, costs can be shared and thus be low, hence the attractiveness for the automotive industry.

To operate, PPP uses a feature available in most modern vehicles - that is connectivity. Cellular communications allow the downloading of correction data that is computed with the positioning information processed by a GNSS receiver. The algorithms using the PPP signals output location estimates with an accuracy of a few centimetres, which respond to the needs of autonomous driving.

This paper presents state-of-the-art in positioning technologies valid for the autonomous driving requirements. It focuses on a solution to exploit the possibilities of GNSS systems based on on-board connectivity. The manner how this solution is implemented and verified in public roads as part of the ESCAPE project is detailed.

The ESCAPE project, funded by the European GNSS Agency, researched around the referred technologies with the aim to develop a precise positioning system for autonomous vehicles. ESCAPE applies PPP corrections to the GNSS data processed by an advanced dual frequency multiple constellation GNSS receiver. PPP corrections are downloaded from the Internet through the cellular link that the unit provides. They are combined with vehicle odometer data and other on-board sources. The system outputs high accurate positioning, velocity and time (PVT) information together with integrity information in the form of protection levels. The latter is needed to satisfy the safety requirements of autonomous vehicles.

The developed system was designed to respond to the positioning needs of autonomous vehicles, nevertheless its capabilities can be used too in different types of driving assistance systems. The advanced positioning features in the ESCAPE system can be an invaluable aid to maximize the use of regulation services such as the emergency call.

The availability of precise position is an enabler for applications requiring spatial-temporal information like in the case of vehicle to vehicle and vehicle to infrastructure communication technologies. Further the coming 5G networks shall enable other applications.

## **1. Introduction**

Positioning techniques have been present in vehicles for longer than many of us could imagine. It was at the beginning of the last century when the first inventions appeared to help in navigation, but positioning systems based on satellite information did not appear until the 1980s.

Over the years following its appearance, GNSS navigation systems barely evolved with a relevant impact for users. It is true that for the use they were given, the service offered was sufficient. However, their accuracy was always one of the great inconveniences they presented. Although advances at a technical level for users go unnoticed, the implementation of these systems was popularized thanks to the emergence of alternative systems to GPS, such as Glonass and Galileo, and especially to the emergence of navigation devices at moderate prices for the mass market.

The automotive industry is currently in process of change. The technological innovation that is taking place in recent years leads to a rethinking of the vehicles engineering at all levels. One of the biggest challenges to which the industry is exposed is to make autonomous driving vehicles a reality, and this will involve an evolution of all the car's systems, including positioning and navigation. For a vehicle to be autonomous, it needs means with which to recognize the surroundings in the absence of a driver who can perceive the stimuli coming from it. Cars will need a large display of sensors to detect obstacles or unexpected elements on the road, but ultimately knowing their absolute position will be essential to guide the driving routes.

The navigation devices that are nowadays available in the mass market, as well as the ones that car manufacturers integrate in their vehicles, do not provide the performance levels that the car of the future will demand. As a starting requirement, it is essential to consider that the car will have to estimate its position within the exact lane of the road in which it is really located, and this translates into an accuracy below half a meter. Of course, it will also be necessary to ensure good accuracy in the longitudinal direction of the car, as this will allow decision making for the maneuvers to be executed. Finally, although less obvious, the accuracy in the vertical position will become also essential to resolve the position of the car on roads at several levels.

On the other hand, not only the accuracy is relevant for an autonomous vehicle, but also other features come to the fore when talking about driverless cars. Continuity, availability, robustness and integrity are mandatory features for safety critical applications. Reaching the key performance parameters according to the mentioned needs is a challenge for the automotive industry. This is a sector that presents some constraints linked to the industrialization of products, their integration into vehicles and their cost.

First of all, it should be noted that vehicles have a very reduced space to integrate the positioning system. This leads to a possible trend for the coming years: all the information related to positioning could be centralized in a single Electronic Control Unit (ECU) that would serve the rest of the vehicle's

components. This approach would allow not only to optimize the integration of the car's electronic systems in terms of space, but also to ensure that the different ECUs use the same position information.

The dimensions of a GNSS-based positioning system should therefore be reduced, and this involves some limitations on the receiver. The GNSS receiver chipsets specially developed for the automotive market present some particular features that go through having a low consumption, operating under a wide range of temperatures, presenting a reduced cost and, for autonomous driving applications, also a safety design.

The requirements on reduced cost and dimensions also impact on the GNSS antenna. This is an aspect that does not have an adequate solution today, because despite existing on the market different solutions for vehicles, they are usually antennas that do not have a good performance or support a very limited number of frequency bands.

In this scenario, GNSS system providers have to exploit the most advanced techniques that allow reaching the level of requirements demanded by the market, since the existing solutions implemented in other more advanced sectors in this area, such as aviation, are not directly portable due to the stated limitations.

The position estimated by a GNSS receiver is affected by various sources of error, especially in low-cost receivers such as those used in automotive. Estimating a position with good accuracy involves applying corrections to the measurements obtained from GNSS satellites. There are augmentation techniques known as "differential GNSS" that are very popular and used in many sectors; this is the case of RTK. The problem with these techniques is that despite achieving good results, they require the deployment of a large infrastructure. It is estimated that an RTK-based system would require the installation of base stations at a distance of no more than 20 km, so to achieve a worldwide deployment for roads this solution becomes unfeasible. [RD.2][RD.3]

There is another approach that skips this constraint: the PPP technique, which rely on GNSS satellite clock and orbit corrections, generated from a network of global reference stations. Once the corrections are calculated, they are delivered to the end user via satellite or over the Internet. With this technique, the infrastructure is drastically reduced compared to that required by RTK, making it suitable for road applications. A PPP solution can achieve accuracies at the decimeter level, which may be sufficient for the autonomous vehicle requirements described above. The technique needs an initial convergence time to solve local biases, but this problem is being solved nowadays thanks to the emergence of improved techniques that are being developed. [RD.2][RD.3]

## 2. ESCAPE project

ESCAPE is a project started in 2016 whose objective is to develop a positioning system that, under all the constraints described above, enables safety-critical automotive applications such as autonomous driving. The project, funded by the European GNSS Agency (GSA) under the European Union's Fundamental Elements research and development program, brings together European partners from the automotive and GNSS sectors who have been investigating the most optimal way to integrate a high-performance solution with a reduced cost.



Figure 1 - ESCAPE Project partners

Within this purpose, the ESCAPE project has two important objectives. First, aligned with the launch of the first services of the Galileo satellite network, this solution aims to exploit the benefits of the European positioning system. Galileo is a system that allows users to position themselves more accurately than with GPS, with the incentive of operating under civil control. In addition, it offers the OS-NMA authentication service, which allows recipients to detect when spoofing attacks may occur.

On the other hand, the project has focused on reaching a solution suitable for applications with safety needs, so it provides an integrity layer as the most relevant performance feature.

The project does not merely seek to devise a solution on paper; it has gone through all the development phases until producing mature prototypes of the unit that have been finally integrated into real cars. Developing an almost-finished product makes possible to evaluate the performance of the system in different scenarios, and allows assessing the viability of the solution that will be brought to the market.

### 3. ESCAPE system elements

ESCAPE system brings together different advanced positioning techniques. The application algorithms are based on the fusion of sensors present in the vehicle, which provide relative positioning information: cameras, map information and other data sources available from the car's communication buses. It should be noted that the system reuses elements that will be found in any vehicle of the future but also in early prototypes that we can see today, with hardly any impact on the price paid by the end user of the vehicle. This has been a decisive criterion when choosing the data sources fused by the ESCAPE engine.

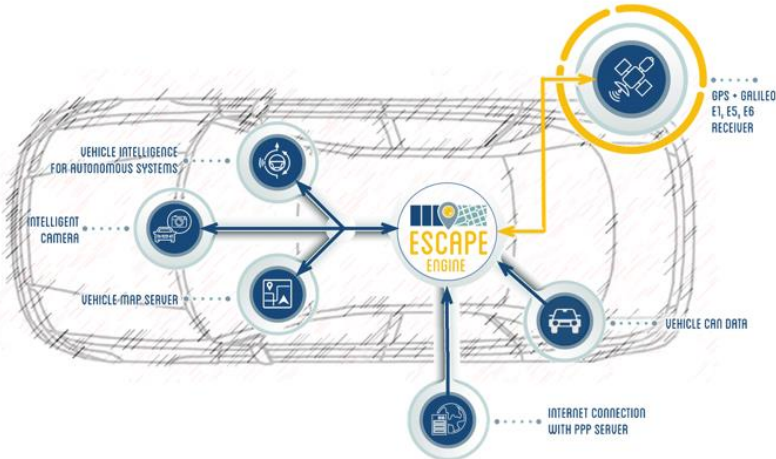


Figure 2 - ESCAPE system and elements in vehicle

The system has been designed as an on-board unit (OBU) that is integrated like any other ECU of the vehicle. The OBU, developed by the automotive supplier Ficosa, implements several communications interfaces to receive data from the different sources as well as to output the estimated positioning, velocity and time (PVT) and synchronization signals to the vehicle. Most of the information is exchanged through CAN and Ethernet buses. The OBU provides also serial ports and LTE cellular communications.

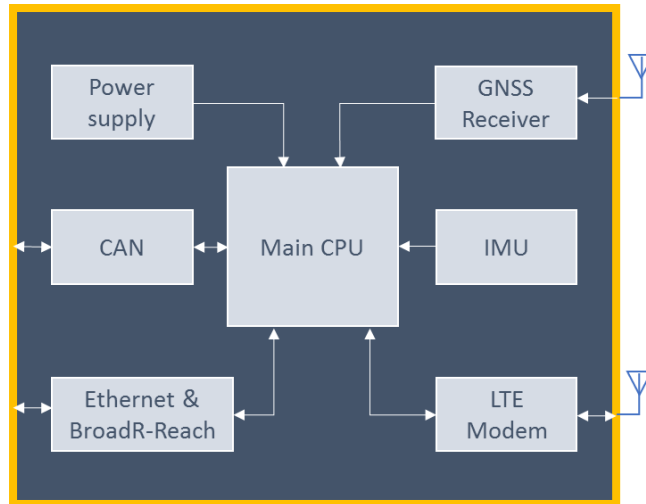


Figure 3 - Hardware architecture

The essential component of the unit is an advanced GNSS receiver from the silicon manufacturer STMicroelectronics, which supports dual frequency and multiple constellations. The device has been developed as an integrated circuit specifically for automotive applications, thus reducing product dimensions, consumption and cost. The receiver, named Teseo ASIL Precise Positioning (APP), is a dual-frequency measurement engine capable of processing signals from Galileo, GPS, Glonass, BeiDou, QZSS and IRNSS constellations. The ESCAPE unit has been designed so that, through different configurations, Teseo APP can support the frequency bands L1-L2-L5 of GPS and E1-E5a-E5b of Galileo.

One of the techniques implemented by the algorithms is Dead Reckoning (DR), which makes use of inertial information to estimate positions from previously determined samples. To this end, the hardware unit also provides an Inertial Measurement Unit (IMU), consisting of an accelerometer and a gyroscope.

Two positioning algorithms developed by the company GMV run at the core of the engine [RD.4]:

- In one hand, an algorithm that computes GNSS and IMU measurements in order to provide a GNSS pose with integrity. This position is computed by combining Standard Point Positioning (SPP) and Precise Point Positioning (PPP) techniques. The PPP algorithm exploits an Internet connection to a remote server to get sets of precise corrections for the GNSS navigation: when available, the PPP service is able to reach decimeter-level positioning accuracy.
- A second camera-based algorithm, enabled by the information of accurate maps containing road lane-marks. These maps along with the intelligent camera measurements allow a second positioning service with accuracies that can reach a few centimeters in the cross direction, thus complementing and enhancing the positions provided by GNSS and sensors. Measurements from vehicle sensors that provide – among others – speed and yaw rate, are also used to reach the maximum possible accuracy.

As already explained, the PPP technique requires to download a stream of corrections from a server. To make this possible, the system relies on LTE communications enabled by the modem that is integrated in the OBU.

The system finally computes high accurate PVT information that is delivered to the intelligence of the vehicle, who will be responsible for making use of this information or discard it when the integrity of the data is not guaranteed. This latter is possible because the unit delivers, together with each PVT estimate, the protection levels (PLs), which refer to the confidence one can give to the correctness of the estimate with respect to the true - but unknown - quantity. The PLs are computed with a technique known as KIPL (Kalman Integrated Protection Level), based on the idea of dynamically modeling the

different components of the positioning error with a properly parameterized error probability distribution. Each distribution is processed and updated separately and provides a contribution to the total error probability. Finally, the protection level is computed as the maximum error level whose probability is below a given integrity risk. [RD.4]

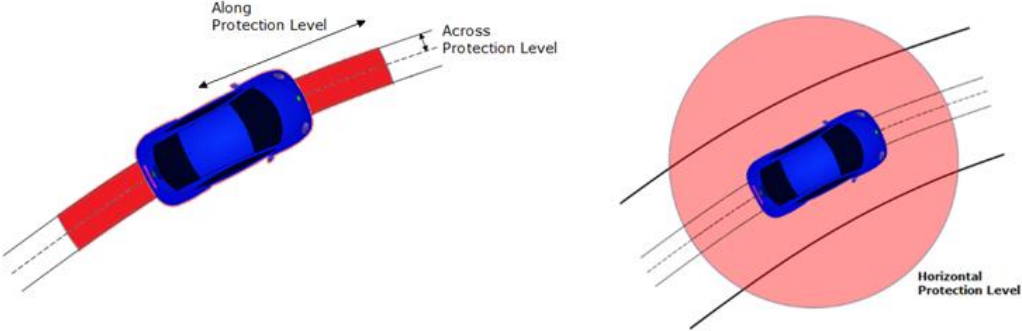


Figure 4 - Protection Level associated to an estimated position

#### 4. ESCAPE applications

The primary application of the ESCAPE solution is to deliver positioning data for safety critical functions in the vehicle. Within the framework of the project, the unit has been developed with the target of being integrated and evaluated in a vehicle of the car manufacturer Renault. This vehicle implements real autonomous driving functions, which is the first application that benefits from the high accuracy position provided by the system.

However, it is noticeable that this benefit can also be exploited by other automotive applications that require reliable and accurate position information. For example, one of the areas where many initiatives are currently on-going is the Smart Mobility. In this context, vehicle fleet management is increasingly necessary. Today, car rental fleets coexist in the cities with rental services that include drivers, as well as shuttles and delivery fleets. An efficient management of these vehicle fleets can be achieved with advanced positioning systems. Traffic management can also benefit from them to ensure sustainability in the cities.

On the other hand, the end user can also benefit directly from other positioning applications. This is the case of payment services such as road user charging or insurance telematics. In these services, a significant deviation in the estimated position may result in an increase in costs, either for end users or service managers. For these environments, companies will clearly bet on reliable and highly accurate systems with reasonable market prices.

The relevance of good positioning for regulated services should be also highlighted. Until today, an accuracy of a few meters had been widely accepted as sufficient for applications such as the emergency call. But there is no doubt on the benefit that an accuracy guaranteed below one meter would bring in some particular situations. We can imagine, for example, two way roads with separated lanes: if an accident occurs, communicating a position that is affected by some meters of inaccuracy can lead to the emergency services accessing the place from the wrong direction, thus delaying the assistance.

#### 5. Evolution of GNSS in vehicles

The highly accurate positioning described in this paper is largely enabled by the presence of connectivity in the vehicle, which makes possible to download GNSS corrections that greatly improve

position estimates. Connectivity opens many possibilities to exploit applications based on cooperative communications.

In the case of vehicle-to-vehicle and vehicle-to-infrastructure communications, known as V2X, efficient communication between vehicles and the environment is enabled by the ability of the vehicles to be located correctly and therefore to identify the other elements around it. But V2X communications can also become a source of information for positioning: a vehicle can estimate its position based on the relative information obtained from the vehicles and infrastructure around them.

On the other hand, the work that is ongoing for defining 5G networks has also a focus on positioning. There are many reasons to think on 5G positioning as a very promising technique. However, most probably the perfect solution will not rely on a single technology; some technologies will work for certain scenarios but not for the others, so the right combination of different techniques will be the key.

In conclusion, the evolution of accurate positioning systems for vehicles should be aimed in the near future to search for hybrid solutions that optimize the combination of all the available sources of information. 5G and cooperative communications will ask for accurate position to operate effectively, while at the same time they will act as a reliable source of information.

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