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ACCURATE: multi-sensor fusion for enhanced L4/L5 positioning

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Abstract

The ACCURATE project (H2020 GSA Fundamental Elements 2020 - 2022) will develop a high-precision positioning onboard unit (OBU), that can be integrated in systems required by any car, truck or bus OEM. Is is based on tight heterogenous sensor fusion that will be easily integrable on Automated Driving Systems (ADS) for any vehicle for reaching SAE L4 and L5 automated driving levels. Due to the inherent difficulty of solving the "self-driving car problem", an ADS requires complex software and hardware system architectures. These systems are expected to operate safely even in the event of system failures or hazardous external conditions such as poor weather. An ADS must be able to achieve a minimal risk condition (such as pulling over to the side of the road) if it detects any issues with its own functionality or external conditions that prevent further safe operation. ACCURATE will provide an enhance Operational Design Domain (ODD) for automated driving functionalities. Additionally, special attention will be paid to the certification process of positioning requirements and higher levels of automated driving. ACCURATE will also study how to include the EGNSS-based positioning technologies in the validation channel by making use of the advanced simulation and scenario generation tools where not only the scene and vehicles dynamic are simulated, generating a digital twin, but also the constellation, and where the EGNSS signal's impact related to the specific scenario are also considered. This is motivated by the fact the increased complexity in validating emerging technologies implemented in Connected and Automated Driving (CAD) vehicles is one of the biggest barriers for its market introduction. The actual validation is based on specific scenes and maneuvers related to aiding driving functionalities where only relative positioning was required.

Keywords

AUTOMATED DRIVING, ADAS, SAE-L4/5, POSITIONING, EGNSS, SENSOR FUSION.

Introduction

Driverless technology is expected to add 7 Trillion USD to the global economy and save hundreds of thousands of lives in the next few decades. Simultaneously, it will cause wholesale upheaval in the automotive industry and its secondary and tertiary sectors not to mention Petrol and

Services Stations, Taxi Drivers, Trucker Drivers, even fast-food drive-throughs. Some people will prosper. Most will benefit. Many will have to adjust their careers or be left behind.

Europe is a key player in this game: the automotive industry is one of the main pillars of the European Economy. European Bus, Truck and Automaker OEMs and Tier1 providers are very well positioned and cover a high percentage of the global market shares. However, a huge technology effort is required so as not to miss the trains of the automated vehicle race as they leave the station. Not only the emergent US technology giants that are positioning above Tier1s and creating new breeds of OEMs, but also emerging economies are positioning themselves free from the regulatory and societal guarantees we cherish in Europe (e.g., China).

However, there is still a long way to go, although there are some SAE L3/L4 prototypes [1][2], there is a lack of consensus on how to certify and standardize the requirements of these high levels of automated driving and absolute EGNSS-based positioning systems[3] have not been given enough importance. Amongst the myriad of pieces in the automated driving jigsaw puzzle, the place for positioning must be found.

In today's SAE L3/L4 systems, localization of vehicles on a map is generally done based on using some previously created high definition (HD) map. Scalable updates of these HD maps are challenging, because they are mostly based on proprietary algorithms and hence HD maps from one vendor do not work with others. Accurate EGNSS allows precise georeferencing of map information. With a low cost and scalable accurate GNSS, the many challenges with HD map updates may be resolved, since the information can be collected and combined from various sources, such as fleet vehicles, public utility vehicles, and so on.

Accurate EGNSS based positioning technology will be a key factor for high levels of automation, since in the lower levels (L0-L3) navigation and the partial responsibility of the location still fall on the drivers. At the moment, geo-positioning is a convenience, allowing us to know where we are in relation to certain objects, in the future, geo-positioning will no longer be a convenience, it will be a critical requirement for automation.

Thus, highly automated vehicles require precise and reliable absolute positioning and here the European Galileo Satellite Navigation System plays a crucial role. Galileo multi-frequency signals, including E5, E6, wide-band and pilot signals, offer important benefits, such as enabling centimetre-level accuracy, better multipath mitigation, and protection against spoofing. The 20-centimetre accuracy that Galileo (high accuracy service) will provide will bring a revolution in active safety and will enable cooperative, connected, automated mobility by providing lane level positioning, which is of utmost importance and something that the industry has been waiting for, and has tried to overcome by including extra sensors. The benefits of high accuracy EGNSS-based positioning in autonomous navigation is well suited for dynamic state estimation and can contribute to cooperative driving. EGNSS will be an important element, providing increased redundancy. Galileo offers outstanding availability and accuracy. The Galileo authentication and high accuracy services will have an enormous positive impact in many areas, including autonomous driving.

Finally, on the path toward total driving automation, certification and standardization will play an important role. All functions of assistance and automation that have been certified up to now have only required a relative positioning and not absolute. In this aspect Europe also has experience with the lessons learnt from the eCall system [4] in which Galileo and EGNOS play a key role.

Objective

In this context, ACCURATE will pave the way towards the development of a precise positioning system for high levels of automated driving SAE-L4 and L5 for many vehicle types (e.g., cars, buses, trucks) pursuing the following objectives:

- Development of close-to-production automotive onboard unit (OBU) prototype for EGNSS based positioning.

- Use of accuracy and integrity of the EGNSS components and services in a multi system and multifrequency specially taking advantage of E5a and E5b.
- Hybrid implementation of differential GNSS techniques, PPP (Precise Point Positioning) and RTK (Real Time Kinematic), inside OBU.
- Tight fusion of on-board perception sensors (including LiDAR, camera, radar) and OBU precise position outputs for localization and mapping.
- Handling adverse weather conditions (rain, snow, …) by utilizing EGNSS that is not impacted by weather.
- A level of confidence on the position level that is based not only on EGNSS measurements (as traditional integrity parameters do) but on the combination of all positioning information sources and enhanced maps.
- Integration with the vehicle Telematics and Control Units.
- Safety-critical approach from design: certification in accordance with the automotive industry functional-safety standard ISO 26262.
- Inclusion of EGNSS technologies in L4 and L5 validation and certification pipelines.
- Design and calculation of impacts and parameters required from the positioning system and how data fusion and other positioning systems will ensure the localization level required to enable L4 and L5.
- Urban/Highway scenario capable. In highway environments, EGNSS plays more role and in urban environments perception sensors.

Concept

ACCURATE proposes the building of a tightly fused positioning unit combining EGNSS multifrequency, correction signals and LIDAR based computer vision analysis to enhance the calculation of ego vehicle dynamics. This positioning system will be prepared to feed the Autonomous Driving Platform that will perform the driving functionalities by interpreting the scene. The system is based on existing, and specifically, automotive grade sensors and chipsets, some of which are yet to reach the market and will be made available to the consortium as pre-releases through its partners. ACCURATE should be ISO26262 compliant to meet the automotive industry's standard for functional safety.

The following are the main components of ACCURATE Positioning Platform (see Figure 1):

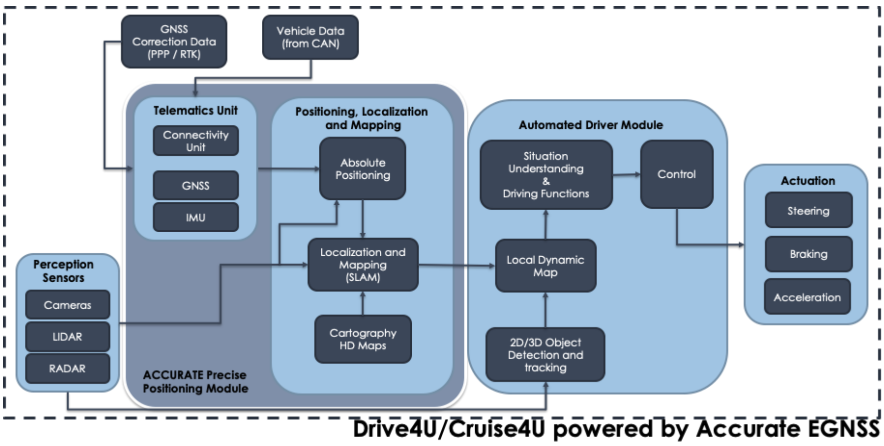

Figure 1: Conceptual block diagram of the technological developments

ACCURATE Precise Positioning Platform for automotive sector is formed by two main blocks 1) the Telematic Unit and 2) Positioning Localisation and Mapping Unit.

The telematics unit is formed by the connectivity unit that is responsible for receiving the correction data provided by a hybrid approach of PPP and RTK (Hexagon TerraStar-X has been selected for PPP correction data) to balance the convergence time required by the PPP approach and the infrastructure / service costs of a correction system. In urban areas where the signal can easily be lost, the RTK option will offer less convergence time, while in suburban environments where the signal is more direct, a PPP approach will be chosen. The connectivity unit will collect the vehicle data from the CAN bus and make them available to calculate the absolute position. The Telematics Unit will also include the multi-frequency (E1/E5 including E5 AltBOC) EGNSS chipset to provide higher EGNSS raw data quality. This data will be then processed by algorithms to combine with the PPP and RTK corrections.

Position Localization and Mapping unit is the responsible of the hybridisation of the heterogenous signals to calculate the precise vehicle position relative to the map that will be feeding the automated Driver Module. First the EGNSS raw measurements will be combined with the all correction information provided by the PPP corrections the perception sensor input such us LIDAR and cameras will be used to design a robust and accurate positioning solution for handling all situations (weather, urban canyons, tunnels, etc.). The 3D point cloud generated by the LIDAR will be the basis to calculate a precise SLAM solution. The proposed approach will evolve from the traditional robotics domain SLAM to a Deep learning base location and mapping extraction to be tightly fused with the position and dynamics calculated with the raw EGNSS data. This approach will be combined with a similar radar-based SLAM approach for redundancy and robustness and camera inputs will be used to ensure the lane level positioning using computer vision-based detectors. With this hybrid approach the availability and precision of the position in all conditions is ensured.

The calculated position is then combined with the cartography information to build the e-horizon to be provided to the Automated Driver Unit which will combine the location positioning with the multisensor perception algorithms to understand the driving situation and the evolution and generate the control and actuation orders.

GNSS-based absolute position

The GNSS-based technologies play a central role on absolute positioning estimation. In contrast to mass-market consumer applications (navigation systems without integrity or safety standards), the ACCURATE system faces much higher requirements regarding accuracy, integrity, availability and reliability of the positioning solution. In Autonomous Driving, we need absolute positioning to locate the vehicle in a map. In order to locate the vehicle inside a specific lane (sub-lane level), the positioning error must be much lower than the lane width and significantly lower than the car width.

ACCURATE uses a GNSS-based positioning unit based on three main elements:

1. STM TeseoAPP: the first Multi-Constellation, Multi-Band GNSS Receiver with Autonomous-Driving Precision and Automotive Safety Compliance. The receiver provides high accuracy positioning at the decimetre and centimetre-level for PPP and RTK applications which are a requirement from ACCURATE Project. Teseo APP provides high-quality raw GNSS data for PPP (Precise Point Positioning) and RTK (Real Time Kinematic) algorithm, which allows accurate positioning and rapid convergence time worldwide.
2. Hexagon’s TerraStar X GNSS correction technology. Standard PPP (i.e. carrier phase GNSS with minimal correction data, such as satellite orbit error) has long convergence time, in the order of hours or several minutes. Hexagon TerraStar-X solution can achieve much faster convergence time, in the order of one to two minutes, by providing an expanded and more accurate set of correction data, that are derived from a network of

ground-based stations, spaced at about 100 km apart.

3. Hexagon's SWPE (Software Positioning Engine), which can work with multiconstellation and single or multiple frequencies (L1, E5a/b) and includes precise positioning algorithms: Precise Point Positioning (PPP) and Satellite Based Augmentation System (SBAS).

ACCURATE proposes a PPP based solution that is based on Hexagon TerraStar-X solution for open sky environments and RTK-PPP for dense and populated regions. When vehicle moves out of a dense region, RTK fix helps PPP to converge much faster.

Enhanced absolute position with sensor fusion

For a L4 or L5 Autonomous Driving application it is essential to obtain not only a high absolute positioning accuracy, but also high levels of integrity and availability. Unfortunately, GNSS alone cannot solve the problem of obtaining acceptable levels of accuracy, integrity and availability for autonomous driving. The GNSS-based positioning performance strongly depends on the accuracy of the range measurements and the geometry of the visible satellites. To ensure a good performance in constrained environments, GNSS needs to be combined with other sensors.

In the ACCURATE approach two levels of sensor fusion are performed: first use 6-axes MEMS IMU, 3- axes for accelerometer and 3-axes for gyroscope. Fusion of GNSS, IMU, and vehicle data (including wheel ticks, speed, and forward/reverse direction) from CAN bus will be done by a dead reckoning (DR) algorithm that is part of the positioning engine running inside OBU. In GNSS challenged environments, positioning error of DR grows by time and distance, because of various noises in accelerometer, gyroscope, and vehicle data. In a second step the remaining error will be reduced by adding an extra step of fusion with a robust multi-LIDAR based position triangulation. To add robustness against external factor a Radar based triangulation will also be included to ensure the maximization of the ODD of the positioning solution. Finally a extra layer based on camera based perception will add the lane level detections cues to ensure the driving within the lanes. The ACCURATE solution is going to be deployed in Valeo's Drive4U car, that comes with 5 cameras, 4 radars, and 8 Scala laser scanners, that will be employed for further positioning refinement and localisation.

Vehicle localisation for Highly Automated Driving

Absolute positioning can only determine the position of the ego vehicle in the world, but it cannot perceive the environment around the vehicle. The Highly Automated Driving technology requires the information of the position relationship between the ego vehicle and other road entities, such as the distance between the vehicle and the road edge or the stop line.

On board perception sensor technologies, such as camera, LIDAR, Radar, and ultrasonic have been deeply studied. Some of them have achieved promising results for precise positioning and navigation. LIDAR can capture features with reliable resolution at the distance of up to 100 meters, camera is usable to detect close environment about 30 meters and in order to acquire 360-degree field of view, combination of multi- camera is needed. Radar has large sensor range (200 m), however it provides few information about the features and will be interrupted by weather condition such as rain.

Maps are often integrated with the sensors to provide road information within a long distance. However, the application of current commercial maps is limited by their low accuracy and simple representation of road network. One of the emerging autonomous driving technologies is the High-definition map (HD map) which provides high precision data on the road features and is a common approach to fulfil the range and accuracy requirements of autonomous driving

SLAM technique is currently one of the mostly studied strategies for autonomous driving with HD maps as it can determine the location of the ego vehicle and the relationship between the ego vehicle and other entities around it at the same time. SLAM technique can also contribute to the update of the HD map in cloud with the real-time road condition

The ACCURATE positioning OBU fuses the absolute positioning estimated with the sensor fusion module with Valeo's Scala Lidar based SLAM solution to accurately locate the vehicle in a HD map. If necessary, Radar SLAM and/or camera-based techniques can also be used to enhance the localisation. The selection of the Scala Lidar has been made with the final objective of developing a real product to be deployed in any vehicle, since the Scala Lidar is the first laser scanner for the automotive volume production. The use of other LIDARs would be valid from the research point of view but difficult to evolve into a real deployable product.

Operational Design Domain Extension

The main purpose of the ODD is to precisely specify the domain in which the Autonomous Driving System (ADS) can safely perform the Dynamic Driving Task (DDT). SAE J3016 introduced this concept in order to capture limitations for driving automation at levels 1, 2, 3 and 4. The factor affecting the ODD are:

- The road environment
- The behaviour of the ADS-equipped subject vehicle
- State of the vehicle

The Restricted Operational Domain (ROD) is the specific conditions under which a given driving automation system or feature thereof is currently able to function. The ROD is a system degradation concept, which allows restricting the ODD of a driving automation system or its feature based on the current capability of the system. The factors affecting the Operational Design Domain are among others i) Sensor performance, ii) Communication needs and performances, iii) Performance in mixed traffic, iv) Control System performance and v) ability to handle the unexpected.

The ODD is usually described as follows:

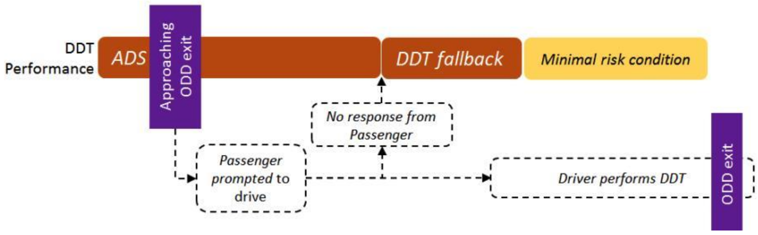

Figure 2: ODD Description

Depending on the Operational Road Environment (OREM), the vehicle sensors and the situation the ADS will be limited asking the driver to take back control again or driving in a DDT fall back for an emergency manoeuvre minimizing risks.

The objective of ACCURATE Project is to maximize the Operational design domain to go beyond the current limiting factors such as weather conditions, road conditions by enhancing the situation awareness by combing high precision positioning approach with camera, lidar and radar perceptions systems.

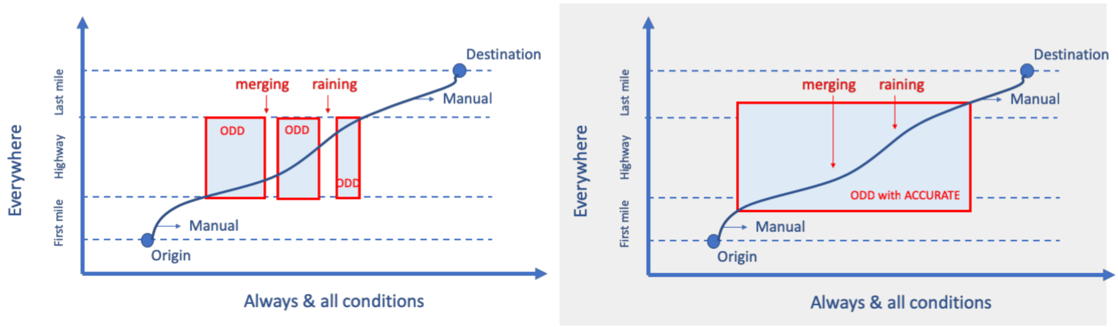

Figure 3: ODD 2D representation

Validation and certification

ACCURATE will also focus on the process required to validate and certify and serve as guideline for higher level of automated driving. The certification and validation methods for L4 and l5 are not yet defined and a lot of work remains to be done in the area. Testing autonomous vehicles usually starts in a confined area, with open sky conditions and minimal multipath interference. However, this type of environment does not reflect real-world conditions when EGNSS signals are blocked by trees, buildings, overpasses or other obstructions.

However, is crucial to include in the validation pipeline specific tests and measurements to certify the positioning system of the vehicle. The industry is focused on recording a large number of driving kilometres needed to develop robust and efficient autonomous driving models, the use of driver-in-the-loop and high- performance computing simulation is essential. However, they again are manoeuvre oriented and not an end-to-end validation process. Thus, this project will work on how to include the validation process for positioning certification in L4 and L5 including real and virtual scenarios.

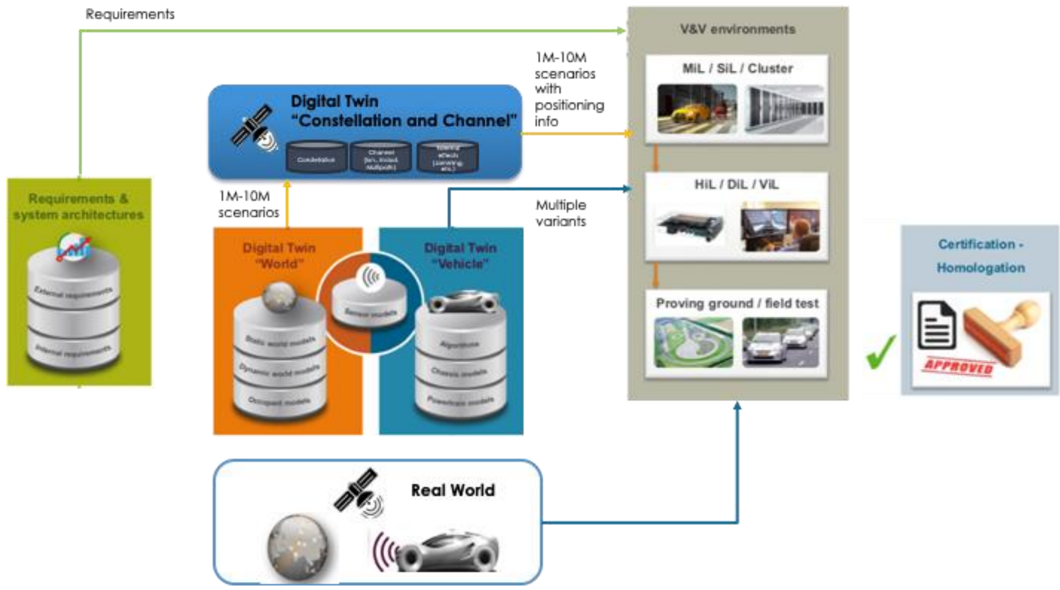

Figure 4 – Testing and Validation Functional Architecture

ACCURATE will help to define testing and validation procedures for L4 and L5 functions including in the test design pipelines key enabling technologies like security and positioning by cross-linking of all test instances such as real recordings and scenes and simulation, providing ground and real-world test fields to validate the safety, security and performance.

The ACCURATE testing will be aligned with the new methodology proposed by HEADSTART Project [5] for testing and validation of highly automated driving functions.

Conclusions

The paper presents the approach of ACCURATE project for the development of a high precision positioning OBU, that can be integrated in systems required by any Car, Truck or Bus OEM, based on tight heterogenous sensor fusion that will be easily integrable on Automated Driving platforms for any vehicle for reaching SAE L4 and L5 automated driving levels.

The paper presents the first architecture proposed for the development of the ACCURATE-OBU where special emphasis has be given to the sensor fusion approach to reduce the absolute error of the position calculation module which will be a key enabler for any automated driving function.

Finally, the approach proposed for validating and certificating the ACCURATE-OBU has been presented. This approach will be aligned with the HEADSTART (H2020) Methodology.

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