



SURFACE VEHICLE INFORMATION REPORT

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High-Precision Positioning for V2X Systems

RATIONALE

High-precision positioning systems—hereafter called HPPS in this SAE Information Report—with an overall submeter positioning accuracy and precision with high confidence (for example, 95%) have become affordable and available for automotive applications in recent years. Vehicle-to-everything (V2X) communication systems, equipped with an HPPS, have the potential to enable and enhance many safety and non-safety related applications.

For this potential to fully materialize, there are opportunities to enhance some of the V2X standards to adopt HPPS in such a way that an HPPS-equipped V2X device be able to fully represent its high precision and trustworthiness information. This full representation will allow the receivers to have adequate data to assess the quality of the data and, if deemed suitable, utilize this information for active safety and mobility applications, such as integration with ADAS or automated driving.

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1. SCOPE

This SAE Information Report identifies some enhancements that may be applied to V2X standards, addressing new use cases that require or benefit from high levels of position precision and integrity.

2. REFERENCES

2.1 Applicable documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2735	V2X Communications Message Set Dictionary
SAE J2945/1	On-Board System Requirements for V2V Safety Communications
SAE J3016	Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles
SAE J3161/1	On-Board System Requirements for LTE-V2X V2V Safety Communications
SAE J3224	V2X Sensor-Sharing for Cooperative and Automated Driving

2.1.2 ESA Navipedia Publications

GNSS PPP Systems	https://gssc.esa.int/navipedia/index.php/Precise_Point_Positioning
GNSS RTK Systems	https://gssc.esa.int/navipedia/index.php/RTK_Systems
GNSS SBAS Systems	https://gssc.esa.int/navipedia/index.php/SBAS_General_Introduction
Integrity	https://gssc.esa.int/navipedia/index.php/Integrity
WGS-84 Reference Frame	https://gssc.esa.int/navipedia/index.php/Reference_Frames_in_GNSS

2.1.3 RTCM Publications

Available from Radio Technical Commission for Maritime Services (RTCM), 1150 18th St NW Suite 910, Washington, DC 20036, Tel: +1 703-527-2000, <https://www.rtcn.org/>.

RTCM 10403.3	Differential GNSS (Global Navigation Satellite Systems) Services
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2.1.4 arXiv Publications

Available from arXiv, <https://arxiv.org/>.

arXiv:1906.01061	Localization Requirements for Autonomous Vehicles
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2.1.5 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

Zhu, N., Marais, J., Bétaille, and Berbineau, M. (2018). GNSS position integrity in urban environments: A review of literature. *IEEE Transactions on Intelligent Transportation Systems* 19(9), pp. 2762-2778, doi: 10.1109/TITS.2017.2766768.

3. DEFINITIONS

BeiDou: China's GNSS system.

CONTINUITY RISK: Probability that over a specified time interval, the integrity of the system is compromised.

EGNOS: Europe's regional GNSS correction service via geo-stationary satellites.

GALILEO: Europe's GNSS system.

GLONASS: Russia's GNSS system.

HOST VEHICLE: Subject vehicle that utilizes received V2X messages to perform a task or maneuver.

INTEGRITY RISK (IR): Probability of providing a position that is out of tolerance without timely warning the user.

INTEGRITY: Measure of the level of trust placed in the correctness of the information supplied by a system.

PROTECTION LEVEL (PL): Upper bound of the error with a probability derived from the integrity requirement.

QZSS: Japan's GNSS system.

REMOTE VEHICLE: A vehicle in vicinity of the host vehicle broadcasting V2X messages.

TIME TO ALERT (TTA): Maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert.

WAAS: USA's regional GNSS correction service via geo-stationary satellites.

4. ABBREVIATIONS AND ACRONYMS

3GPP	Third Generation Partnership Project
5GAA	5G Automotive Association
ADAS	Advanced driver assistance system
AEB	Automatic emergency braking
BSM	Basic safety message
C/A	Coarse acquisition
C-V2X	Cellular V2X
DR	Dead reckoning
DSRC	Dedicated short range communications
EEBL	Emergency electronic brake light

EGNOS	European Geostationary Navigation Overlay Service
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GNSS	Global navigation satellite system
GPS	Global positioning system
HPPS	High-precision positioning system
HV	Host vehicle
IMU	Inertial measurement unit
IRNSS	Indian Regional Navigation Satellite System
LiDAR	Light detection and ranging
MEMS	Micro electro-mechanical systems
MSCS	Maneuver sharing and coordinating service
NRTK	Network real time kinematic
PLL	Phase lock loop
PNT	Positioning, navigation, and timing
PPP	Precise point positioning
RSU	Roadside unit
RTK	Real-time kinematic
RV	Remote vehicle
RVRU	Remote vulnerable road user
SBAS	Satellite-based augmentation systems
SDO	Standards developing organization
SDSM	Sensor data sharing message
SSL	Sensor sharing service
UWB	Ultra-wideband
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
VRU	Vulnerable road user
WAAS	Wide area augmentation system

5. INTRODUCTION

Standard GNSS receivers—which are nowadays ubiquitous in vehicles, smartphones, and many other devices—can achieve about 1.5 m position precision, at a confidence level of 68% (i.e., 1σ), which means that up to 32% of the time the error is greater than 1.5 m. This is yet assuming open sky (e.g., freeway) and under ideal conditions. These ideal conditions include the utilization of satellite-based augmentation system (SBAS) correction data and benign ionospheric conditions in the absence of solar storm and at mid-latitude regions (typically defined between 20 to 60 degrees north and south of the magnetic equator).

GNSS is the generic name encompassing all the satellite-based navigation systems. An early example, and perhaps the best known, of GNSS is GPS, the USA's system which is the oldest and most used system. There are also several other systems (aka constellations), the main ones being: Europe's Galileo, China's BeiDou, Russia's GLONASS, Japan's QZSS, and India's IRNSS.

Although the above-mentioned meter level precision is generally adequate and acceptable for road level navigation, stolen vehicle recovery, and so forth, it is mostly not sufficient for applications that require confident absolute lane level distinction, such as automated driving and V2X advanced driver assistance system (ADAS) fusion, as illustrated in Figure 1. V2X here refers to direct (i.e., ad-hoc) vehicle-to-everything (V2X) wireless communications technologies.

The terms “accuracy” and “precision” are used interchangeably in this report, even though they are technically independent of each other. Accuracy measures how close results are to the true or known value. Precision, on the other hand, measures how close results are to one another. Except when explicitly stated, accuracy in this report implies the combination of accuracy and precision.

The Integrity of the achieved solution is another relevant requirement to be considered.

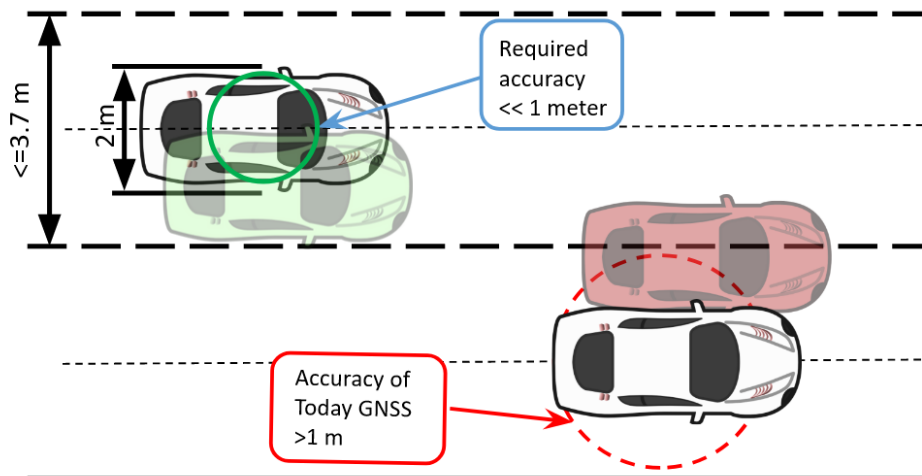


Figure 1 - Submeter accuracy is critical for confident lane determination

6. HPPS USE CASES

Lane level positioning can enhance and enable many V2V (as well as V2I and in general V2X) applications. One example application is active emergency electronic brake light (EEBL), in which the host vehicle (HV) automatically—that is, without human interaction—slows down or brakes in response to EEBL alert from a remote vehicle (RV) ahead, as depicted in the Figure 2. For active braking, it is important that the HV be almost certain that RV is in the same lane as the vehicle ahead. HPPS can enhance use cases, among others, in the following categories:

- V2X-ADAS fusion.
- Lane level sensor and information sharing.
- Cooperative automation platooning.
- Precision docking.
- Garage/fleet management.
- Pedestrian cooperative detection.
- Blind spot warning.
- Vehicle adjacent lane passing.

In all the above categories, it is assumed that the vehicle receiving the V2X information has some level of automation from automatic emergency braking (AEB) to L4 automation (as defined by SAE J3016).

6.1 V2X-ADAS Fusion

Over the past two decades, numerous great applications have been proposed and demonstrated related to using V2X information to issue collision avoidance warnings to drivers. V2X-ADAS fusion here refers to taking these use cases to the next level by having the vehicle automatically act (including braking, acceleration, and steering) to avert the collision or lessen its impact. Such enhancement requires a high confidence on V2X information to lower the risk of false triggers, as much as possible.

As an example (see Figure 2), suppose there is interest in fusing V2V harsh braking information with ADAS AEB. For this application to be successful, the lateral position of the two vehicles relative to each other must be known with adequate accuracy that enables the HV to determine with a very high confidence whether the harsh braking vehicle is in its lane or not.

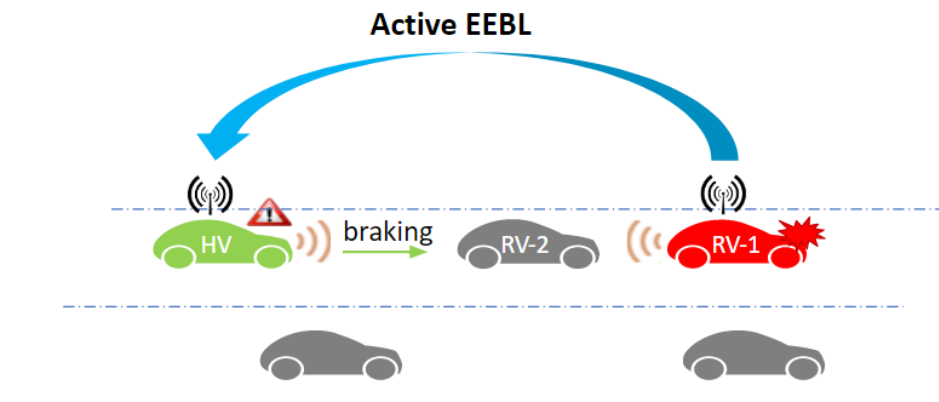


Figure 2 - V2X-ADAS fusion: active EEBL

6.2 Lane Level Sensor and Information Sharing

Sensor sharing between vehicles and road users is a very promising approach and a lot of research and development is currently being carried out in this field. Figure 3 is an example sensor sharing case, in which remote vehicle (RV-1) broadcasts a lane closure alert for other road users. HV receives this alert. Should HV intends to utilize this information for a vehicle action (e.g., slow down or lane change), it would be again critical that the RV-1's information be accurate and at lane level, hence requiring precise positioning.

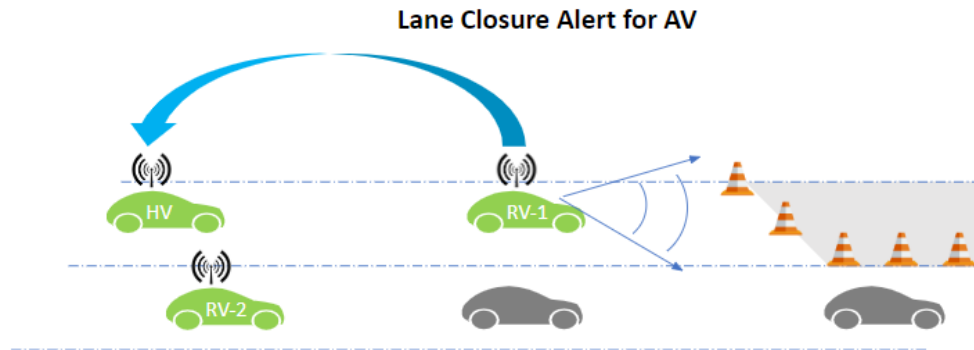


Figure 3 - Sensor sharing: lane closure alert

6.3 Cooperative Automated Platooning

Cooperative automated platooning is another use case that requires or benefits from precise positioning, by enabling the vehicles follow each other in the same lane, as depicted in Figure 4 for HV, RV-1, and RV-2.

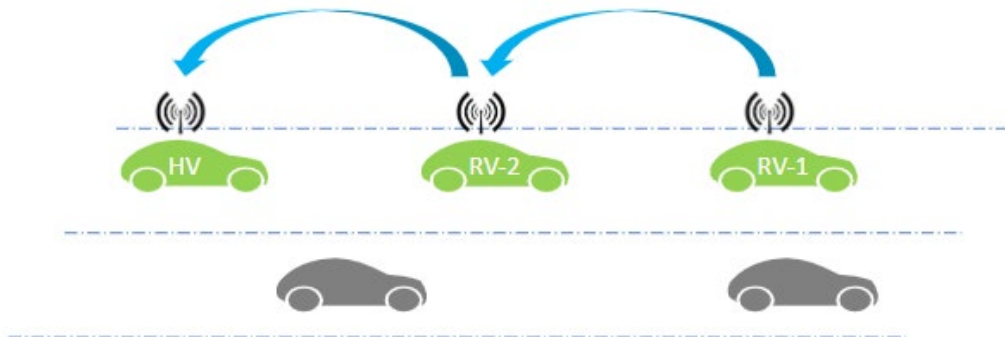


Figure 4 - Platooning

7. POSITIONING PERFORMANCE REQUIREMENTS

In real time, the true value of the position is unknown (as well as other positioning related information, such as speed, heading angle, etc.); hence only an estimate, based on statistical and probabilistic analyses, may be provided. It is important to know with high confidence how reliable this estimate is.

Accuracy and integrity are two of the key information for representing trustworthiness of the data. Integrity is a general performance feature referring to the trust a user can have in the delivered value of a given position or velocity quantity (e.g., horizontal position). For more information about the integrity and how it is represented. Refer to ESA's Integrity document, Zhu et al. (2018), and arXiv:1906.01061.

Some of the estimated values that need to be reported to represent the trustworthiness are:

- Confidence intervals at different levels, including 68%, 95%, and 99%.
- Position error (PE): Position error. This is unknown to the positioning system in real time.
- Protection level (PL): Maximum likely error, estimated by the positioning system in real time. PL should be smaller than the alert limit, or an alert is expected within the time to alert interval.
- Integrity risk (IR): Upper bound on the probability (see equation below) that the position error exceeds the alert level, while PL is smaller than the alert limit for a duration longer than the time to alert:

$$\Pr[(PE > AL) \text{ and } (PL < AL) \text{ for longer than TTA}] < IR \quad (\text{Eq. 1})$$

- Continuity risk: Probability that over a specified time interval (for example in the next 10 seconds), the integrity of the system is compromised.
- Time to alert (TTA): The maximum allowable time for the positioning system to issue an alert, after the error exceeds the alert limit.
- Alert limit (AL): The maximum allowable tolerance limit on the position, that is specified or configured by the user of the system as an input of the positioning system.

For reference, in the aviation sector the integrity risk is typically defined as 2×10^{-7} and TTA is 6 seconds.

A real hazard, called hazardous misleading information (HMI), happens when there is a misleading information and the user is not timely warned.

Note that for automotive applications, the position error, and its associated PL and AL are often separated in horizontal and vertical directions.

The actual minimum positioning accuracy requirement depends on the specific V2X application. Higher precision positioning at decimeter level is generally a requirement anytime that positioning information embedded in an V2X message is utilized directly or indirectly to control the vehicle. The position accuracy information reported in the BSM message may not be useful in its current form, because the means for computing it is not specified in SAE J2735 or SAE J2945/1. Therefore, the results from one implementation to next may be different.

For V2X applications, one approach could be that the positioning system performance is categorized into four classes, as listed in Table 1. Then, for every V2X use case, a reference could be made to one of these performance classes, whenever a positioning information is transmitted.

The classes and their associated limits listed in Table 1 are just examples and based on the sponsor's best knowledge and experience. Note that a positioning system should not be expected to report the same level of precision all the time. Instead, the positioning system must pick the appropriate performance level class, according to the actual performance of the system, given the internal and external conditions, at that time and location. The positioning system may also throttle the limits, utilizing its real time best estimates of those. A general guideline would be that; the top tier high-precision class would deliver low decimeter position accuracy most of the time; the medium precision class delivers submeter accuracy; the normal precision class would be equivalent to what stated in the V2X standards referred to today; and the low-to-poor precision classes would be the degraded performance of the system due to typically environmental conditions.

As an example, suppose the vehicle is equipped with a multi-frequency GNSS-based positioning system and supplied with high-precision GNSS correction data. This system may indeed deliver high-precision performance on an open sky highway, whilst its performance significantly degrades in a deep urban environment. Such system may report high precision as its class of performance on highway and poor precision in deep urban canyon.