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GALILEO HAS OVERVIEW, COMPARISON WITH ANALOGUES, AND ASSESSMENT OF PERSPECTIVE

In 2022, Galileo, the European GNSS, launched the first phase of its HAS (High Accuracy Service) initiative. By providing free and global corrections for clock delays and satellite orbits, Galileo HAS provides decimeter positioning accuracy the need for additional ground networks. This research aims to evaluate the advancements in precise positioning technologies, with a focus on the Galileo High Accuracy Service (HAS). The study highlights the importance of precision positioning methods, including Standard Point Positioning (SPP), Real-Time Kinematic (RTK), and Precise Point Positioning (PPP), and assesses the performance of Galileo HAS in comparison with other global augmentation services like QZSS CLAS and BeiDou PPP-B2b. The methodology involves a comprehensive analysis of technical capabilities, accuracy, and operational limitations of HAS through literature review and comparative analysis of positioning performance data. The results confirm that Galileo HAS achieves decimeter-level accuracy globally, with horizontal accuracy below 20 cm and vertical accuracy below 40 cm, but suffers from prolonged convergence times due to the absence of atmospheric and phase bias corrections in its initial phase. The scientific novelty lies in identifying HAS's potential as the first global free PPP correction service via Signal-in-Space (SIS), distinguishing its practical advantages in semi-enclosed environments compared to traditional PPP augmentation systems. The study also emphasizes the unique integration challenges posed by HAS corrections due to proprietary encoding formats. Practically, the findings underscore HAS's utility in geodesy, mapping, and real-time applications, particularly in resource-constrained settings. However, the research highlights critical areas for improvement, such as implementing atmospheric corrections and phase bias adjustments, to meet real-time precise positioning demands. The conclusions note the undoubted usefulness of such a service as Galileo HAS, review its shortcomings and methods of solving them.

Key words: GNSS, Galileo High Accuracy Service, PPP, RT-PPP, precise positioning, navigation

Introduction

To achieve the required levels of positioning performance and reliability, the best way to combine information from several complementary sources. Among them, global navigation satellite systems occupy a central position due to their ability to provide global location almost anywhere in the open space. Naturally, the requirements for accuracy and reliability of GNSS positioning are also increasing. Several technologies have been developed to achieve this goal, such as precise point positioning (PPP), real-time kinematics (RTK), and more recently a hybridization of both, PPP-RTK. Among the existing GNSS-based positioning methods, RTK is still the most accurate. However, due to their technological complexity and the associated cost, RTK is usually limited to specialized professionals, mainly in the field of geodesy. The “standard” PPP technology is currently used for a wide range of applications but still has insufficient accuracy and a long convergence time.

The growing demand for real-time (RT) positioning prompted the International GNSS Service (IGS) to launch a Real-Time Pilot Project in 2007 and officially launch the Real-Time Service (RTS) in 2013 [Elsobeiey & Al-Harbi, 2016]. There are many factors affecting the accuracy of Real-Time PPP (RT PPP), and successful uncertainty resolution is an effective approach to improve positioning accuracy in real-world environments [Liu et al, 2020; Gao et al, 2023]. However, RT-PPP requires highly accurate orbital and clock products in real time. To solve this problem, satellite navigation system providers are developing their own space-based PPP augmentation systems. For example, China has launched the PPP-B2b augmentation service for the BeiDou Navigation Satellite System (BDS), and Japan has introduced the Centimeter Level Augmentation Service (CLAS) for the Quasi-Zenith Satellite System (QZSS). The CLAS augmentation for QZSS in Japan allows to achieve a positioning error of less than 6.4 cm [Takahashi et al., 2018], while BDS PPP-B2b can provide positioning accuracy at the level of decimeters in real-time kinematics [Yang et al., 2022].

To support this trend, the European Commission and the Galileo project announced the launch of the High Accuracy Service (HAS) on January 24, 2023. This service is intended to be the first globally available PPP correction service using Signal-In-Space (SIS) as a distribution method [Galielo HAS ICD, 2022]. Galileo HAS works basically like any commercial PPP service but with some significant differences. First, the signal is available for free via the Internet or directly through the Galileo E6-B signal. Since the corrections are transmitted from the Galileo satellite rather than from a geostationary communication satellite, it is much easier to receive corrections in semi-enclosed areas such as urban canyons, parkland, etc. A significant technical problem is the limited number of receivers that can implement Galileo HAS.

HAS is expected to become a basic positioning service for many areas, such as aviation, precision agriculture, UAV navigation, maritime, and others. However, the adaptation of such a new service often depends on its availability and usability. In addition, it should be remembered that there are already other similar services on the market, so increasing the availability of HAS and identifying its real positioning accuracy are urgent tasks.

Overview of modern positioning methods

Determining the absolute position of a point is a fundamental task in GNSS positioning. The most common absolute GNSS positioning method is single point positioning (SPP). It is a fundamental GNSS positioning method that determines the user's location by measuring the pseudo-distance of satellite signals. It operates on a single receiver and uses ephemeris and clock data provided by satellites to calculate position, velocity, and time. The pseudo-range equation for SPP can be written as:

$$p_r^S = \varrho_r^S(t) + c\Delta\delta_r^S(t), \tag{1}$$

where p_r^S is the measured pseudo-distance between the receiver r and the satellite S, $\varrho_r^S(t)$ is the geometric distance between the satellite and the receiver, c is the speed of light, and $\Delta\delta_r^S$ represents the combined offset of the receiver and satellite clocks relative to the system time.

SPP is widely used for general navigation and low-precision applications due to its simplicity and global availability [Teunissen & Montenbruck, pp. 612–613]. However, it is limited by errors caused by atmospheric delays, satellite orbit and clock inaccuracies, and multipath effects, which leads to positioning errors that typically range from a few meters to tens of meters, depending on the quality of the receiver and the signal propagation environment.

For three decades, from 1990 to 2020, relative or differential positioning was the leading method for precise positioning and GNSS data processing. In this method, the coordinates of an unknown point are determined relative to another reference point with known coordinates. This approach allows to eliminate or significantly reduce most of the errors of GNSS observations, which are spatially correlated at both points, providing high positioning accuracy [Teunissen & Montenbruck, p. 623].

At the initial stages, the implementation of this technique included one base station and one or more rover receivers operating in the local area in real time. Wich this approach positioning accuracy from the sub-meter to centimeter level could be achieved. Accuracy depended mainly on whether pseudo-range, carrier phase, or a combination of both were used, as well as on the success of ambiguity resolution when carrier phase was used.

Carrier phase processing provides the highest real-time positioning accuracy, which is known as real-time kinematic positioning (RTK). Over the years, RTK has become a standard procedure for high-precision positioning and navigation in industries such as surveying, engineering, and UAV control [Martínez-Carricondo et al., 2023; Manandhar et al., 1999]. This technology allows for centimeter accuracy, which is critical for applications that require high precision.

In order to expand the coverage area and improve the reliability of the service, RTK technology has subsequently moved to the network level, forming the so-called RTK networks or network-RTK [Rizos, 2009]. This became possible due to the creation of regional networks of reference stations that jointly transmit corrections to users over a large area. In this context, an approach known as the Observation State Representation (OSR) is used, where an aggregate correction is transmitted to users. This correction corresponds to the sum of the individual corrections applied to the observations, which allows achieving high accuracy without the need for individual adjustment for each user.

The development of network-RTK and the introduction of OSR have significantly expanded the capabilities of GNSS technologies, allowing for highly accurate real-time positioning over large areas. This opens up new perspectives for applications in autonomous vehicles, fleet management, infrastructure monitoring, and other industries where accurate positioning is a key success factor.

In the traditional PPP (Precise Point Positioning) approach, as in other augmentation methods such as GNSS differential subsystems (e. g., code-based SBAS) or phase differential measurements (e. g., RTK), corrections received from reference stations are required. However, PPP takes a different approach to achieving high accuracy. Instead of directly calculating or transmitting distance corrections, as is done in RTK or SBAS, PPP uses data on precise orbits and time corrections.

For PPP, typically dual-frequency data are combined to eliminate almost all propagation delays in the ionosphere. Combinations of ionospheric-free (IF) dual-frequency GNSS pseudoband (ρ_{IF}) and carrier phase (φ_{IF}) associated with the user's position, clock, troposphere, and uncertainty parameters are determined in accordance with the following simplified observation equations (2) [Teunissen & Montenbruck, p. 724]:

$$\begin{aligned} p_{r,IF}^{s} &= \rho_r^s + c(dt_r - dt^s) + T_r^S + e_{IF} \\ \varphi_{r,IF}^{s} &= \rho_r^s + c(dt_r - dt^s) + \lambda_{IF} A_{IF} + \epsilon_{IF} \end{aligned} \tag{2}$$

where: p_{sr}^{IF} ionosphere-free combination $\frac{f_A^2 p_A - f_B^2 p_B}{f_A^2 - f_B^2}$ of pseudo-distances p_A and p_B observed at two different signal frequencies f_A and f_B; φ_{sr}^{IF} ionosphere-free combination $\frac{f_A^2 \varphi_A - f_B^2 \varphi_B}{f_A^2 - f_B^2}$ of the respective carrier phases φ_A and φ_B; ρ_r^s geometric distance $\| x^s - x_r \|$ from the satellite position $x^s = (x^s, y^s, z^s)^T$ in the epoch of signal emission t_E to the position of the receiver $x_r = (x_r, y_r, z_r)^T$ in the epoch of its reception $t_A \approx t_E + \frac{\rho_r^s}{c}$; dt_r receiver clock offset from GNSS time (taking into account receiver code offsets and delays); dt_s satellite clock offset relative to GNSS system time (including satellite code offsets and delays); c is the vacuum speed of light; T_r^S is a signal delay in the neutral layers of the atmosphere (mainly the troposphere); A_{IF} noninteger uncertainty of the ionospheric-free phase combination, in fact, the ionospheric-free combination with integer uncertainties φ_A and φ_B and noninteger initial phase delays; λ_{IF} is an ionospheric-free combination of phase wavelengths λ_A and λ_B A and B signals (e.g., 10.7 cm for GPS L1 and L2); ϵ_{IF}, e_{IF} are relevant measurement noise components, including multipath combinations of ionospheric pseudo-band and carrier phase.

Since GNSS global orbit/clock parameters are fixed, the satellite's coordinates (x^s, y^s, z^s) and the satellite clock dt^s are assumed to be known.

The reference stations in PPP act as monitoring stations that determine highly accurate ephemeris and time corrections in near real time. These ephemeris, which are much more accurate than the predicted ephemeris transmitted by satellites, are broadcast to end users through various channels. This approach has several advantages: it requires only a small number of reference stations located globally, and the transmitted corrections are universal and applicable to any receiver. In addition, the use of broadcast satellites allows the corrections to be transmitted directly, eliminating the need for cellular communications, whicht is especially useful in regions with limited communications infrastructure. PPP is ideal for applications that require accuracy in the centimeter range, such as surveying and moving object tracking.

However, PPP has certain limitations. Because the method based on processing data from a single receiver, and ambiguity resolution takes time, PPP convergence can take 20 to 40 minutes to achieve horizontal accuracy of less than 10 cm. This time is a significant disadvantage for many real-world applications that require instant access to highly accurate data.

Ephemera for PPP can be obtained either by downloading from the global network (usually with a delay for post-processing) or by broadcasting from communication satellites. However, for global real-time applications, only commercial services have been available for a long time. For example, an exception is QZSS CLAS, which provides local corrections over Asia. Free services, although they exist, are usually designed for post-processing or low-latency operation, which limits their use in operational tasks. Table 1 shows a comparison of Galileo HAS with other PPP augmentation services.

Table 1

Comparative analysis of PPP augmentation services

Parameters	Galileo HAS	QZSS CLAS	BeiDou PPP-B2b
Title	High Accuracy Service	Centimeter-Level Augmentation Service	Precise Point Positioning - B2b Service
Operating systems	Galileo, GPS	Quasi-Zenith Satellite System (Japan)	BeiDou Navigation Satellite System (China)
Declared accuracy	Horizontal: <20 cm, Vertical: <40 cm	Centimeter (1–5 cm under ideal conditions)	Centimeter (1–5 cm under ideal conditions)
Format of corrections	Compact-SSR	Compact-SSR	SSR
Signal range	E6B	L6	B2b
Coverage	Global	Regional	Regional
Type of positioning	RT-PPP	RT-PPP/RTK	RT-PPP
Signal encryption	Open signal, requires compatibility with the receiver	Encrypted for RTK corrections; open signal for PPP	Open signal, requires compatibility with the receiver
Launch date	2022	2018	2019
Requirements for the receiver	Galileo compatibility; Ability to receive signal at E6 frequency	QZSS compatibility	Compatible with BeiDou

Another problem with commercial PPP services is their dependence on vendors. Each vendor uses its own format for corrections, which creates compatibility difficulties, as receivers from different manufacturers usually support only one or two specific formats. This significantly limits the flexibility in choosing a service and creates user dependence on a particular vendor. The development of open standards for PPP correction, as well as the emergence of free global real-time services, significantly expands the use of this technology and increases its availability.

Galileo HAS: current status and research overview

The European Commission announced the launch of the initial operational phase of HAS on January 24, 2023. This service provides corrections broadcast worldwide via the E6 signal and the Ntrip. 2s protocol over the Internet, providing real-time orbit, clock, code and phase offsets for four Galileo frequencies (E1, E5a, E5b, E6) and three GPS frequencies (L1, L2C and L5). At the moment, all of the above corrections (except for phase offsets) can already be obtained with a receiver capable of receiving the E6B signal [Galileo HAS ICD, 2022].

The launch of the HAS service is divided into three stages: Phase 0 (testing and experimentation with HAS), Phase 1 (initial HAS service), and Phase 2 (full service) [Galileo HAS ICD, 2022]. During the testing phase [Hauschild et al, 2022], the effectiveness of HAS was evaluated. The results show that the SISRE values for GPS and Galileo were 12-16 cm and 7-9 cm, respectively. Using data from May 2021, [Fernandez-Hernandez et al, 2022] reported SISRE values of 16 cm and 9.5 cm for GPS and Galileo. Based on an analysis of the accuracy of HAS ephemeris, [Naciri et al, 2023] tested the positioning performance of PPP-HAS in the summer of 2022. The results showed that the standard deviation of horizontal and vertical positioning is less than 20 cm, which meets the expected performance criteria of the service.

As of November 2024, HAS remains in its early stages. At this stage, HAS offers global coverage, making it the first system to provide high-precision positioning services worldwide. At this stage, Galileo's official documents describe HAS positioning accuracy at global stations with a horizontal accuracy of less than 20 cm (95 %), a vertical accuracy of less than 40 cm (95 %), and a convergence time of less than 300 seconds.

Since the launch of the first phase of Galileo HAS, a large number of papers have been published on product evaluation, positioning accuracy, and convergence time studies under various conditions using HAS. The authors of [Hadas et al., 2024] confirm that Galileo HAS provides real-time orbit and clock correction accuracy comparable to correction streams from the Internet, making it a promising alternative for GNSS-based geoscience applications, even though performance is somewhat reduced outside the service area. For example, in [Pintor et al., 2023], the authors obtained HAS correction data on board a buoy-laying vessel from July 2023 to August 2023, achieving a horizontal accuracy of 0.22 m after eliminating sea disturbances. In [Cucchi et al., 2024], HAS corrections were used to process PPP in open areas and in dense buildings, respectively, proving that positioning accuracy can be improved when using HAS corrections. Study [Yi et al., 2024] proposes a mobile phone positioning algorithm based on a combination of HAS correction and ephemeral PPP and proves that this algorithm can significantly reduce positioning errors when used in urban navigation. The authors of [Timote et al, 2024] demonstrated that the requirements of Galileo HAS are achieved in a real-time ionospheric correction system based on PPP, showing positioning accuracy with horizontal and vertical errors of 10–30 cm and 20–50 cm, respectively.

Table 2 provides an overview of the results of PPP positioning accuracy studies with Galileo HAS.

Table 2

The results of studies of positioning accuracy and convergence time of HAS

Research	Positioning strategy	Horizontal accuracy	Vertical accuracy	Convergence time
Naciri et al., 2023	RTPPP in kinematic mode. Separately, the results using only GPS, Galileo, and both were studied	**GPS:** >30 cm **GAL:** 15.6 cm **GPS+GAL:** 13.1 cm	**GPS:** >40 cm **GAL:** 22.4 cm **GPS+GAL:** 17.6 cm	**GPS:** >40 min **GAL:** 10 min. **GPS+GAL:** 7.5 min
Hadas et al., 2024	RTPPP in kinematic mode on a moving ship	**GPS+GAL:** 29 cm	**GPS+GAL:** 42 cm	Not analyzed
Cucchi et al., 2024	RTPPP in static mode in dense buildings	**GPS+GAL:** 19 cm	**GPS+GAL:** 17 cm	43 min
Savchuk et al., 2024	RTPPP in kinematic mode in the open	**GPS+GAL:** 17 cm	**GPS+GAL:** 39 cm	18 min
Fernandez-Hernandez et al., 2022	RTPPP in static mode	**GPS+GAL: 8 cm**	**GPS+GAL: 8 cm**	Not analyzed

From the above data, it follows that the absolute accuracy of coordinate determination using Galileo HAS corrections corresponds to that stated in [Galileo HAS ICD, 2022]. However, the convergence time remains insufficient for real-time PPP applications. This is mainly due to the lack of corrections for phase bias and atmospheric effects in this stage of HAS.

Several software products have been developed to integrate HAS for real-time measurements. For example, an open source HAS correction decoding package in C/C++ was developed in [Zhang et al., 2024]. HASPPP can be easily embedded into common C/C++-based software, such as RTKLIB. Similar software was developed by the authors of [Horst et al., 2022]. In [Borio et al., 2023], a Python software package was developed to read HAS data from raw observation files of different receivers and convert them into a more convenient and readable format for further analysis or comparison with other products. Fig. 1 demonstrates the process of obtaining real-time coordinates using the PPP method with HAS corrections used in [Horst et al., 2023; Savchuk et al., 2024].

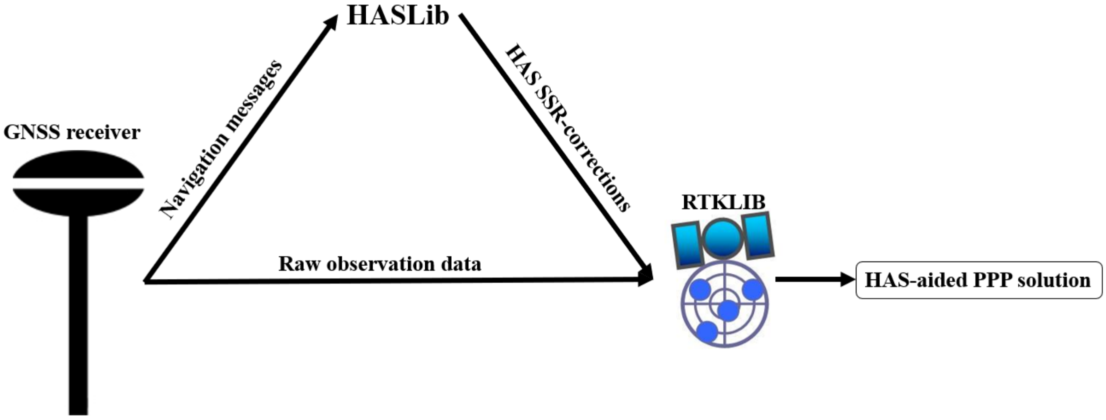

Fig. 1. Scheme of workflow with RTKLib and HASLib to obtain a HAS-aided PPP solution

Although this approach is convenient because it does not require the user to edit existing software or create new software, it has its drawbacks. One of these disadvantages is that RTKLib does not support SSR corrections for code bias, which causes underutilization of the resources provided by HAS. It is also unclear how correctly the HAS corrections are interpreted in RTKLib and how they are interpolated during the period of absence. Another negative factor of this approach is that the presence of additional software in the form of HASLib for decoding and formatting corrections can create delays in their transmission and application, which can greatly affect convergence time.

Discussion

Problems related to HAS

The Galileo HAS high-precision service aims to provide precise positioning with decimeter accuracy using corrections transmitted via the Galileo signal and the Internet. While this is a significant advancement in GNSS technology, its current implementation is fraught with a number of challenges.

The most important problem at the moment is the lack of atmospheric and phase shift corrections. Currently, Galileo HAS is in the first stage of implementation (Fig. 2), and therefore does not have atmospheric corrections (ionospheric and tropospheric) and phase shift corrections.

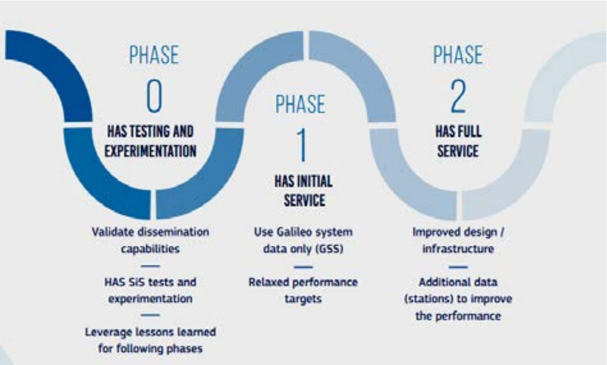

Fig. 2. Stages of implementation of the Galileo HAS service [Galileo HAS Info Note]

This shortcoming limits its usefulness in providing full-scale accurate PPP positioning. Users must rely on external atmospheric correction models, such as global ionospheric maps, off-the-shelf ionosphere and troposphere models (e. g., the Saastamoinen tropospheric delay model), or estimate the influence of atmospheric effects during the observation process. Phase-shift corrections are critical to resolving ambiguity, which is necessary to achieve high-precision solutions. Without them, users face longer convergence times or cannot achieve the promised accuracy[Savchuk et al., 2024]. The introduction of the second stage of HAS will solve these problems, but according to [Galileo HAS Info Note, 2020], the launch is planned after 2024.

Another disadvantage is the complex structure of corrections. Galileo HAS encodes corrections using the vertical Reed-Solomon scheme and provides them as corrections to the state space representation (SSR) [Galileo HAS ICD]. Reed-Solomon encoding provides optimal data archiving for fast transfer, but its implementation adds complexity for developers and users, especially in decoding and verification [Fernandez-Hernandez et al., 2022].

SSR – State-Space Representation – is a relatively new concept for providing correction data in real-time kinematic precision positioning systems (PPP-RTK). Instead of providing combined corrections in the observed space, as in OSR (Observed Space Representation), the SSR approach uses decomposed corrections to eliminate individual sources of GNSS errors [Schmitz, 2012]. These include satellite position corrections (in three dimensions) and satellite clock corrections, as well as code shifts. Different types of messages are supported for separate or combined orbit and clock corrections. In addition, separate high-speed clock correction messages are available to ensure that satellites with rapidly changing atomic clocks can be accurately located. The SSR concept also provide for the provision of Vertical Total Electronic Content (VTEC) information for single-frequency users.The generic nature of SSR corrections makes them largely independent of the user's location and provides the basis for global PPP applications [Teunissen & Montenbruck, p. 1216].

SSR corrections are not yet widely supported in popular GNSS processing software and are not fully integrated into standard workflows due to the lack of a commonly accepted standard. It should be noted that HAS corrections are provided in a proprietary format similar to Compact-SSR. It follows that it is impossible to directly apply Compact SSR format corrections in software such as RTKLib [Takasu, 2013], since it only supports the full-fledged RTCM SSR format.

By addressing these issues, Galileo HAS will be able to better position itself as a competitive, affordable solution in the global market for high-precision GNSS solutions.

Using HAS in geodesy

The Galileo HAS high-precision service offers significant potential for geodesy, surveying and mapping, albeit with significant limitations due to its current decimeter accuracy. These industries require varying degrees of accuracy, and while HAS is not yet sufficient for applications requiring centimeter accuracy, it provides a framework for certain tasks and opens up opportunities for wider adoption.

For geodesy, the potential of HAS lies primarily in non-critical operations. Tasks such as general land use mapping, preliminary site surveys, or infrastructure planning can benefit from the availability and cost-effectiveness of HAS corrections. While high-precision cadastral boundary determination or building axis establishment remains out of reach, HAS can reduce reliance on expensive equipment or subscription-based services for lower accuracy tasks. Its accessibility via E6 signals and the Internet ensures wide availability, making it particularly attractive to emerging markets or developing regions where geodetic resources are limited.

In cartography, HAS is a promising tool for creating and updating maps that do not require sub-meter accuracy. Applications such as environmental monitoring, urban planning, and general purpose topographic mapping can use its corrections to improve positioning accuracy over standard GNSS. The ability to achieve decimeter accuracy in real time is particularly beneficial for dynamic mapping applications such as mobile mapping systems or unmanned aerial vehicles (UAVs) used to survey large areas.

An important sector of HAS application is civil aviation and shipping. It is expected that the aviation industry will continue to implement high-precision navigation services to further improve the safety and efficiency of its air traffic control services [Savchuk et al., 2024]. The above applies to a wide range of maritime applications, such as navigation, seabed mapping, underwater exploration, search and rescue operations, offshore drilling, and pipeline laying. The HAS service will become an indispensable tool for achieving high accuracy in these industries.

Despite these prospects, the decimeter accuracy of HAS puts it at a disadvantage for the highest accuracy applications, which remain dependent on services that offer centimeter corrections, such as RTK or PPP with phase shift correction. For surveyors and surveying professionals, HAS can currently serve as an additional system rather than a primary solution. However, with the development of the service and integration of additional corrections, such as atmospheric and phase corrections, its relevance for these disciplines will increase, potentially bridging the gap between decimeter and high-precision needs. For mapping applications, where the accuracy threshold is often more flexible, HAS is already a significant advantage, especially in resource-constrained or large-scale projects.

Conclusions

The Galileo HAS high-precision service is an important step in the development of GNSS, offering users around the world freely available data at the decimeter level of accuracy. Its introduction opens up new opportunities for a wide range of applications, from geospatial mapping and environmental monitoring to precision agriculture and autonomous navigation. By transmitting corrections directly over the E6 signal and the Internet, HAS reduces dependence on ground infrastructure and commercial correction services, democratizing access to improved positioning accuracy.

Despite current limitations, such as the lack of corrections for atmospheric and phase shifts and the reliance on SSR corrections that are not yet widely supported, HAS provides a solid foundation for further technological development and integration. Its potential to improve access to high-precision positioning, especially in remote or underserved regions, underscores its value to global initiatives in sustainable development, resource management, and transportation.

Future advances, including the addition of complex corrections and improved software integration, are likely to bridge the gap between HAS and existing high-precision GNSS solutions. As the service evolves, it has the potential to transform workflows in professional fields such as surveying, topography and mapping, fostering innovation and expanding the scope of GNSS applications.

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ОГЛЯД GALILEO HAS, ПОРІВНЯННЯ З АНАЛОГАМИ ТА ОЦІНКА ПЕРСПЕКТИВ

У 2022 р. Galileo, європейська ГНСС, запустила перший етап своєї ініціативи HAS (High Accuracy Service). Надаючи безкоштовні та глобальні поправки на затримки годинників та орбіти супутників, Galileo HAS забезпечує дециметрову точність позиціонування без необхідності використання додаткових наземних мереж. Це дослідження має на меті оцінити досягнення у технологіях точного позиціонування, з акцентом на службі Galileo HAS. Дослідження підкреслює важливість методів точного позиціонування, зокрема одноточкового позиціонування (SPP), кінематичного позиціонування в реальному часі (RTK) і високоточного позиціонування точки (PPP), а також оцінює продуктивність Galileo HAS порівняно з іншими глобальними службами доповнення PPP, такими як QZSS CLAS і BeiDou PPP-B2b. Методологія передбачає комплексний аналіз технічних можливостей, точності та експлуатаційних обмежень HAS на основі огляду літератури та порівняльного аналізу даних про ефективність позиціонування. Результати підтверджують, що Galileo HAS досягає дециметрової точності по всьому світу, з горизонтальною точністю нижче за 20 см і вертикальною точністю нижче за 40 см, але має недоліки тривалий час збіжності через відсутність поправок на атмосферні і фазові зсуви на початковому етапі. Наукова новизна полягає у визначенні потенціалу HAS як першої глобальної безкоштовної служби коригування PPP через Signal-in-Space (SIS), виокремленні її практичних переваг у напівзакритих середовищах порівняно з традиційними системами покращення PPP. Дослідження також підкреслює унікальні проблеми інтеграції, пов’язані з коригуванням за допомогою HAS через особливі формати шифрування. На практиці результати дослідження підкреслюють корисність HAS у геодезії, картографії у разі використання у реальному часі, особливо в умовах обмежених ресурсів. Однак у дослідженні висвітлено критичні недоліки, які потрібно виправити, такі як впровадження атмосферних поправок і коригування фазового зсуву, щоб задовольнити вимоги точного позиціонування в реальному часі. У висновках відзначено безперечну корисність такого сервісу, як Galileo HAS, розглянуто його недоліки та методи їх виправлення.

Ключові слова: GNSS, Galileo High Accuracy Service, PPP, RT-PPP, точне позиціонування, навігація.

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