INTERNATIONAL STANDARD

ISO 24246

First edition
2022-06

Space systems — Requirements for global navigation satellite system (GNSS) positioning augmentation centers

Reference number
ISO 24246:2022(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In the initial decades of the 21st century, several countries provide their constellations of global navigation satellite system (GNSS) such as U.S. GPS, Russian GLONASS, European Galileo, Chinese BDS, Indian NavIC, Japanese QZSS and SBASs; and they have been utilized as an international public service. GNSS positioning applications have been expanding in each region across the world.

In order to maximize the capability of these GNSS constellations, the respective regions have deployed GNSS positioning augmentation centres with continuously operating reference station (CORS) network. These facilities generate different types of corrections to mitigate atmospheric propagation errors and satellite errors, as well as providing integrity information. The application of these augmentation functions helps to achieve higher performance for GNSS positioning.

Along with the development of the GNSS constellations, GNSS reference stations have been established across populous and economic areas of the world. Industrialized countries have adopted precise positioning thanks to this integrated GNSS infrastructure in global, regional and national areas. Positioning users in other parts of the world require similar GNSS infrastructure.

This document is intended to resolve the issue that the users in other areas of the world need similar infrastructure and aims to provide high-performance GNSS standards for users around the world.

ISO TC 20 has published "ISO TC 20 business plan 2015" (https://www.iso.org/committee/46484.html). In 2.1.2 of the business plan, TC 20 has specified that "Space systems are defined as Space segments, Ground Segments and services (or applications)"; namely, space systems are defined to include the service or application.

In the past ten years, ISO TC 20/SC 14/WG 1 has discussed the standardization of space-based services based on "ISO TC 20 business plan 2015", because space systems provide a huge merit for the economy and society in each country today and space-based services contribute to people's quality of life across the world. Space systems should be utilized furthermore in the world industry also after this time.

Today, the market has required precise navigation for automated craft and vehicles. One of the most important requirements is the safety of navigation. In response to this requirement, the space systems community is determined to take leadership of the use of space systems such as GNSS, for other downstream areas of application and service. ISO TC 20/SC 14 and its WG1 collaborate and cooperate with TC 20/SC 13, other ISO TCs, IEC TCs and harmonize the standards by international organizations in the GNSS-relevant area shown as Figure 1.

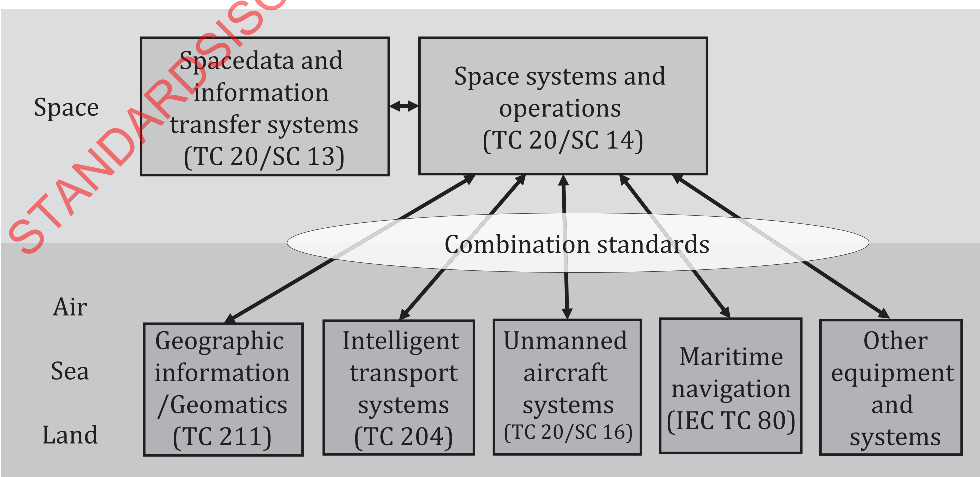


Figure 1 — Standardization of space-based services (GNSS-relevant area)

The GNSS project of ISO has respected the International Committee on Global Navigation Satellite Systems (ICG) and the Global Geospatial Information Management (GGIM) of the United Nations (UN) and its achievements. The UN's recommendations are reflected in this document.

This document is applicable in the civil and commercial market. Because these markets increasingly require high accuracy positioning utilized in automated flight, driving and navigation, it is necessary to standardize GNSS positioning augmentation centres in this document.

ISO TC 20/SC 14 already published ISO 18197, which specified the total matters of system engineering, On the other hand, this document has focused on GNSS positioning augmentation centres as one element of GNSS centimetre class positioning. For the realization of the actual infrastructure, both ISO 18197 and this document should be used.

GNSS applications are emerging industry. Space systems appears to be reaching to incorporated other activities beyond space and aircraft platform for navigation. High performance positioning which is described in this document contributes the safety of navigation after this time.

Space systems — Requirements for global navigation satellite system (GNSS) positioning augmentation centers

1 Scope

This document specifies requirements for GNSS positioning augmentation centres that distribute correction data to provide higher accuracy and integrity information for positioning users in the civil and commercial market.

The GNSS positioning augmentation centres cover the following types of positioning:

a) real-time sub-meter to decimetre-level positioning;

b) real-time centimetre-level positioning;

c) post-processed geodetic positioning.

This document also specifies roles of the following stakeholders and functions of the software present at GNSS positioning augmentation centres:

— role of planner;

— role of designer;

— role of administrator;

— function of software.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 18197, *Space systems — Space based services requirements for centimetre class positioning*

ISO 19161-1:2020, *Geographic information — Geodetic references — Part 1: International terrestrial reference system (ITRS)*

Annex ICAO, 10 – Aeronautical Telecommunications – Volume I – Radio Navigation Aids.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Space-based positioning and navigation

3.1.1
radiodetermination
determination of the position, velocity, timing and/or other characteristics of an object, or the obtaining of information relating to these characteristics, by means of radio waves

[SOURCE: IEC 60050-725:1994, 725-12-48, modified — "timing" has been added.]

3.1.2
satellite radiodetermination
radiodetermination (3.1.1) which makes use of a satellite system

[SOURCE: IEC 60050-725:1994, 725-12-49]

3.1.3
radionavigation
radiodetermination (3.1.1) used for the purpose of navigation, including obstruction warning

[SOURCE: IEC 60050-725:1994, 725-12-50]

3.1.4
satellite radionavigation
satellite radiodetermination (3.1.2) used for *radionavigation* (3.1.3)

[SOURCE: IEC 60050-725:1994, 725-12-51]

3.1.5
universe of discourse
view of the real or hypothetical world that includes everything of interest

[SOURCE: ISO 19101-1:2014, 4.1.38]

3.1.6
positioning augmentation centre
centring system that augments the function of another infrastructural positioning system

Note 1 to entry: An administrator of positioning augmentation centre is a person or a organization who operates, maintains, and responds to users on the service of the above centre.

3.2 Positioning quality

3.2.1
accuracy
closeness of agreement between a test result or measurement result and the *true value* (3.2.5)

Note 1 to entry: In practice, the *accepted true value* (3.2.6) is substituted for the true value.

Note 2 to entry: The term "accuracy", when applied to a set of test or measurement result, involves a combination of random components and a common systematic error or *bias* (3.2.2) component.

Note 3 to entry: Accuracy refers to a combination of bias and *precision* (3.2.3).

[SOURCE: ISO 3534-2:2006, 3.3.1, modified — In Note 1 to entry, "accepted reference value" has been changed to "accepted true value"; in Note 3 to entry, "trueness" has been changed to "bias".]

3.2.2
bias
difference between the expectation of a test result or measurement result and a *true value* (3.2.5)

Note 1 to entry: Bias is the total systematic error as contrasted to random error. There may be one or more systematic error components contributing to the bias. A larger systematic difference from the true value is reflected by a larger bias value.

Note 2 to entry: The bias of a measuring instrument is normally estimated by averaging the error of indication over an appropriate number of repeated measurements. The error of indication is the: “indication of a measuring instrument minus a true value of the corresponding input quantity”.

Note 3 to entry: In practice, the *accepted true value* (3.2.6) is substituted for the true value.

[SOURCE: ISO 3534-2:2006, 3.3.2 modified — In Note 3 to entry, "accepted reference value" has been changed to "accepted true value".]

3.2.3
precision
closeness of agreement between independent test/measurement results obtained under stipulated conditions

Note 1 to entry: Precision depends only on the distribution of random errors and does not relate to the *true value* (3.2.5) or the specified value.

Note 2 to entry: The measure of precision is usually expressed in terms and imprecision and computed as a standard deviation of the test results or measurement results. Less precision is reflected by a larger standard deviation.

Note 3 to entry: Quantitative measures of precision depend critically on the stipulated conditions. Repeatability conditions and reproducibility conditions are particular sets of extreme stipulated conditions.

[SOURCE: ISO 3534-2:2006, 3.3.4]

3.2.4
integrity
measure of the trust that can be placed in the correctness of the information supplied by a navigation system and that includes the ability of the system to provide timely warnings to users when the system should not be used for navigation

[SOURCE: 2019 Federal Radionavigation Plan,[36] DOT-VNTSC-OST-R-15-01, A.1.10]

3.2.5
true value
value which characterizes a quantity or quantitative characteristic perfectly defined in the conditions which exist when that quantity or quantitative characteristic is considered

Note 1 to entry: The true value of a quantity or quantitative characteristic is a theoretical concept and, in general, cannot be known exactly.

[SOURCE: ISO 3534-2:2006, 3.2.5, modified — Note 2 to entry has been deleted.]

3.2.6
accepted true value
value that serves as an agreed-upon reference for comparison

Note 1 to entry: The accepted true value is derived as:

a) a theoretical or established value, based on scientific principles;

b) an assigned or certified value, based on experimental work of some national or international organization;

c) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or technical group;

d) the expectation, i.e. the mean of a specified set of measurements, when a), b) and c) are not available.

[SOURCE: ISO 3534-2:2006, 3.2.7, modified — The term has been changed from "accepted reference value" to "accepted true value".]

3.2.7
state space
space defined by the state variables as axes of a vector space, in which every vector represents a state of the system

Note 1 to entry: A vector space is defined in IEC 60050-102:2017, 102-03-01.

Note 2 to entry: "space" is this term is a mathematical vector space, and if different from "space" of a physical universe.

[SOURCE: IEC 60050-351:2013, 351-41-09, modified — Notes 1 and 2 to entry have been added.]

3.3 Terrestrial reference system

3.3.1
coordinate
one of a sequence of numbers designating the position of a point

Note 1 to entry: In a spatial *coordinate reference system* (3.3.3), the coordinate numbers are qualified by units.

[SOURCE: ISO 19111:2019, 3.1.5]

3.3.2
coordinate system
set of mathematical rules for specifying how *coordinates* (3.3.1) are to be assigned to points

[SOURCE: ISO 19111:2019, 3.1.11]

3.3.3
coordinate reference system
coordinate system (3.3.2) that is related to an object by a *datum* (3.3.4)

Note 1 to entry: Geodetic and vertical datums are referred to as reference frames.

Note 2 to entry: For geodetic and vertical reference frames, the object will be the Earth. In planetary applications, geodetic and vertical reference frames may be applied to other celestial bodies.

[SOURCE: ISO 19111:2019, 3.1.9]

3.3.4
datum
parameter or set of parameters that realize the position of the origin, the scale, and the orientation of a *coordinate system* (3.3.2)

Note 1 to entry: "Reference frame" is an alias of "datum" in the field of geodesy (see SOURCE). But in space systems area, "reference frame" means a platform-fixed coordinate system of a spacecraft or a space station. Therefore, "reference frame" is not used as an alias of "datum" in this document.

[SOURCE: ISO 19111:2019, 3.1.15, modified — The alternative preferred term "reference frame" has bee deleted; note 1 to entry has been added]

3.3.5
coordinate operation
process using a mathematical model, based on a one-to-one relationship, that changes *coordinates* (3.3.1) in a source *coordinate reference system* (3.3.3) to coordinates in a target coordinate reference system, or that changes coordinates at a source coordinate epoch to coordinates at a target coordinate epoch within the same coordinate reference system

[SOURCE: ISO 19111:2019, 3.1.8]

3.3.6
coordinate transformation
coordinate operation (3.3.5) that changes *coordinates* (3.3.1) in a source *coordinate reference system* (3.3.3) to coordinates in a target coordinate reference system in which the source and target coordinate reference systems are based on different *datums* (3.3.4)

Note 1 to entry: A coordinate transformation uses parameters which are derived empirically. Any error in those coordinates will be embedded in the coordinate transformation and when the coordinate transformation is applied the embedded errors are transmitted to output coordinates.

Note 2 to entry: A coordinate transformation is colloquially sometimes referred to as a 'datum transformation'. This is erroneous. A coordinate transformation changes coordinate values. It does not change the definition of the datum. In this document, coordinates are referenced to a coordinate reference system. A coordinate transformation operates between two coordinate reference systems, not between two datums.

[SOURCE: ISO 19111:2019, 3.1.12]

3.3.7
ellipsoid
reference ellipsoid
<geodesy> geometric reference surface embedded in 3D Euclidean space formed by an ellipse that is rotated about a main axis

Note 1 to entry: For the Earth the ellipsoid is bi-axial with rotation about the polar axis. This results in an oblate ellipsoid with the midpoint of the foci located at the nominal centre of the Earth.

[SOURCE: ISO 19111:2019, 3.1.22]

3.3.8
mean sea level
<geodesy> average level of the surface of the sea over all stages of tide and seasonal variations

Note 1 to entry: Mean sea level in a local context normally means mean sea level for the region calculated from observations at one or more points over a given period of time. To meet IHO, standards that period should be one full lunar cycle of 19 years. Mean sea level in a global context differs from a global *geoid* (3.3.9) by not more than 2 m.

[SOURCE: ISO 19111:2019, 3.1.41]

3.3.9
geoid
equipotential surface of the Earth's gravity field which is perpendicular to the direction of gravity and which best fits *mean sea level* (3.3.8) either locally, regionally or globally

[SOURCE: ISO 19111:2019, 3.1.36]

3.3.10
vertical datum
datum describing the relation of *gravity-related heights* (3.4.5) or *depths* (3.4.6) to the Earth

Note 1 to entry: In most cases, the vertical datum will be related to *mean sea level* (3.3.8). Vertical datums include sounding *datums* (3.3.4) (used for hydrographic purposes), in which case the *heights* (3.4.3) may be negative heights or depths.

Note 2 to entry: *Ellipsoidal heights* (3.4.4) are related to a three-dimensional ellipsoidal *coordinate system* (3.3.2) referenced to a geodetic datum.

[SOURCE: ISO 19111:2019, 3.1.72, modified — The alternative preferred term "vertical reference frame" has been deleted and the term “reference frame” has been replaced to “datum”]

3.3.11
terrestrial reference system
set of conventions defining the origin, scale, orientation and time evolution of a spatial reference system co-rotating with the Earth in its diurnal motion in space

Note 1 to entry: The abstract concept of a TRS terrestrial reference system is realized through a terrestrial reference frame that usually consists of a set of physical points with precisely determined *coordinates* (3.3.1) and optionally their rates of change. In this document terrestrial reference frame is included within the geodetic reference frame element of the data model.

[SOURCE: ISO 19111:2019, 3.1.66]

3.3.12
global coordinate reference system
coordinate reference system (3.3.3) that covers a globe

3.3.13
national coordinate reference system
coordinate reference system (3.3.3) that a certain nation defines

3.4 Positioning results

3.4.1
geodetic latitude
angle from the equatorial plane to the perpendicular to the *ellipsoid* (3.3.7) through a given point, northwards treated as positive

[SOURCE: ISO 19111:2019, 3.1.32]

3.4.2
geodetic longitude
angle from the prime meridian plane to the meridian plane of a given point, eastward treated as positive

[SOURCE: ISO 19111:2019, 3.1.33]

3.4.3
height
distance of a point from a chosen reference surface positive upward along a line perpendicular to that surface

Note 1 to entry: A height below the reference surface will have a negative value.

Note 2 to entry: Generalization of *ellipsoidal height* (3.4.4) and *gravity-related height* (3.4.5).

[SOURCE: ISO 19111:2019, 3.1.38]

3.4.4
ellipsoidal height
distance of a point from the *reference ellipsoid* (3.3.7) along the perpendicular from the reference ellipsoid to this point, positive if upwards or outside of the reference ellipsoid

Note 1 to entry: Only used as part of a three-dimensional ellipsoidal *coordinate system* (3.3.2) or as part of a three-dimensional Cartesian coordinate system in a three-dimensional projected *coordinate reference system* (3.3.3), but never on its own.

[SOURCE: ISO 19111:2019, 3.1.24]

3.4.5
gravity-related height
height (3.4.3) that is dependent on the Earth's gravity field

Note 1 to entry: This refers to, amongst others, orthometric height and normal height, which are both approximations of the distance of a point above the *mean sea level* (3.3.8), but may also include normal-orthometric heights, dynamic heights or geopotential numbers.

Note 2 to entry: The distance from the reference surface may follow a curved line, not necessarily straight, as it is influenced by the direction of gravity.

[SOURCE: ISO 19111:2019, 3.1.37]

3.4.6
depth
distance of a point from a chosen vertical reference surface downward along a line that is perpendicular to that surface

Note 1 to entry: The line direction may be straight, or be dependent on the Earth's gravity field or other physical phenomena.

Note 2 to entry: A depth above the vertical reference surface will have a negative value.

[SOURCE: ISO 19111:2019, 3.1.17]

3.5 Cyber security

3.5.1
interference
radio-frequency interference
degradation of the reception of a wanted signal caused by a radio-frequency disturbance

Note 1 to entry: The English words "interference" and "disturbance" are often used indiscriminately. The expression "radio-frequency interference" is also commonly applied to a radio-frequency disturbance or an unwanted signal.

Note 2 to entry: Various levels of interference are defined for administrative purposes in the ITU Radio Regulations viz. permissible interference, accepted interference and harmful interference.

[SOURCE: IEC 60050-713: 1998, 713-11-05, modified — The preferred term "interference" has been added.]

3.5.2
jamming
deliberate *interference* (3.5.1), caused by emissions intended to render unintelligible or falsify the whole or part of a wanted signal

[SOURCE: IEC 60050-713:1998, 713-11-23]

3.5.3
spoofing
impersonating a legitimate resource or user

[SOURCE: ISO/IEC 27033-1:2015, 3.38]

3.5.4
meaconing
interception and rebroadcast of *radionavigation* (3.1.3) signal

4 Abbreviated terms

3GPP	3rd Generation Partnership Project (mobile communication)
AGNSS	assisted GNSS
BDS	BeiDou Satellite Navigation System (China)
BIH	International Time Bureau, i.e. Bureau international de l'heure
BINEX	BINary EXchange Format
CORS	continuously operating reference station
DGNSS	differential GNSS
DGPS	differential Global Positioning System
GBAS	ground based augmentation system
GLONASS	GLObal NAvigation Satellite System (Russian Federation)
GNSS	global navigation satellite system
GPS	Global Positioning System (U.S.A.)
GRS80	Geodetic Reference System 1980
HTTPS	Hyper Text Transfer Protocol Secure
ICAO	International Civil Aviation Organization
IHO	International Hydrographic Organization
ITRF	international terrestrial reference frame
ITRS	international terrestrial reference system
LPP	LTE positioning protocol
LTE	long term evolution
NavIC	Navigation with Indian Constellation (India)
NTRIP	networked transport of RTCM via internet protocol
OSR	observation space representation
PPP	precise point positioning
QZSS	Quasi Zenith Satellite System (Japan)
RINEX	receiver-independent exchange format
RMSE	root mean square error
RTCM	Radio Technical Commission for Maritime Services
RTK	real time kinematic
SBAS	satellite-based augmentation system

SI	International System of Units
SSR	state-space representation
WGS84	World Geodetic System 1984

5 System overview

The GNSS positioning augmentation centre is a part of the system as shown in Figure 2. The system boundary of the subject GNSS positioning augmentation centre is denoted by the bold-dot outlined box. The augmentation centres shall be supplied with data from the CORS stations and shall output the augmentation data to positioning service for many types of applications. For detailed explanation, see References [40], [55] and [56]. Regarding GNSS constellations and systems, see Annex B.

The augmentation centres shall also have the functions of user service and cyber security as specified in this document, and shall adopt space link or terrestrial link for delivery of augmentation data. User applications include vehicles, craft, persons, etc.

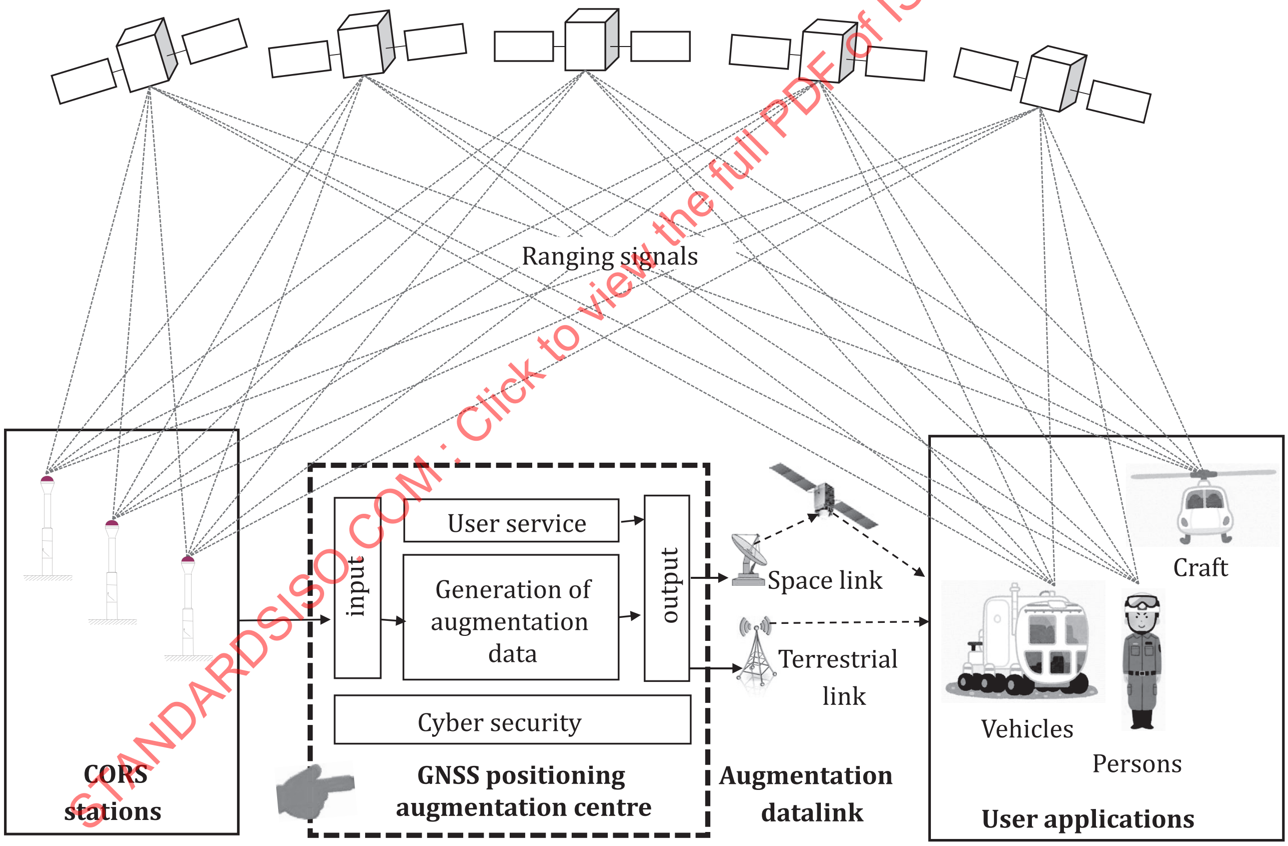


Figure 2 — GNSS positioning augmentation centre and relevant systems

6 Universe of discourse

6.1 General

The planner shall define a universe of discourse for the GNSS positioning augmentation centre using satellite radionavigation technology. The planner can define multiple universes of discourse for the centre.

The concept of “universe of discourse” and its international consensus have been fostered in geographic information and geomatics. This concept is very important for cyber-physical systems in the civil and commercial market in this age, because this term represents the interface between the cyber space and the physical space.

6.2 Scope of users

The planner shall define a scope of users utilizing GNSS space systems. This scope shall be defined not for the availability of providers, but for the convenience of users.

6.3 Service type

The planner shall define one or more GNSS service types from Table 1.

Table 1 — Service type classification of GNSS positioning augmentation centres

No	Classification	Application	Examples
1	Type I	Applications using national coordinate reference system which is the secondary realization of ITRS.	Public surveying, land administration, land transport, civil engineering, oil and gas, etc. (Works under national law enforcement)
2	Type II	Applications using global coordinate reference system which is compliant with the primary realization of ITRS.	Spacecraft navigation, earth observation, marine transport, fishing, oil and gas, public surveying, displacement, positional difference, etc.
3	Type III	Civil aviation	Works with the Chicago Convention of ICAO.
4	Type IV	Extra-standard applications	Private works, special application, etc.

The service type III shall be in accordance with “ICAO Annex 10”. This type has been distinguished from other types, because it specifies strict requirements for the safety of passengers.

Regarding the primary and secondary realizations of ITRS, see ISO 19161-1.

The service type IV is not constrained by this document; but this service can refer this document.

6.4 Service area

The planner shall define a GNSS service area as a geographic region.

6.5 Service time

The planner shall define GNSS service time including date of starting period in year and time of day.

It is recommended to completes the continuous service as follows:

— 365 days in a year;

— 24 hours of a day;

— including intercalary month, day and second.

6.6 Sponsoring organization

Sponsoring organization is an organization that provides right positioning information for users.

Each positioning GNSS augmentation centre shall have a planner, a designer, and an administrator designated; and those roles shall be detailed by the sponsoring organization.

7 Requirements for augmentation services

7.1 General

The planner shall plan to provide the following services for the service area defined in 6. 4.

a) Standard augmentation service

This service shall be provided for real-time applications by using code-based measurements with sub-metre to decimetre- level accuracy in type I, II and III services of 6.3 for navigation.

b) Precise augmentation service

This service shall be provided for real-time applications by using code and carrier-phase measurements, with centimetre-level accuracy in type I and II services of 6.3 with precise navigation and positioning.

c) Geodetic service

This service shall be provided for post-processing applications by using code and carrier-phase measurements in static or kinematic mode, with decimetre to sub-centimetre accuracy in type I and II services of 6.3 with geodetic or surveying quality.

7.2 Standard augmentation service

This service shall adopt and provide one or more services from Table 2 in the service area defined in 6.4. Corrections have two types: OSR and SSR. SSR covers wider area than OSR. Further, these services shall provide integrity information.

Table 2 — Standard augmentation services and their transmitted correction data

Method	DGNSS	
Correction	OSR (e.g. GBAS, DGPS, AGNSS): — Pseudorange — Integrity information [a] At a reference station	SSR (e.g. SBAS): — Satellite clock correction — Satellite orbit correction — Signal bias [a] — Ionospheric correction [a] — Other correction — Integrity information

[a] Optional.

OSR is a representation of correction in observation form such as pseudorange. It is represented as a factor in observation space, which is a mathematical vector space.

SSR is another representation of correction as error factors, such as satellite clock and orbit errors, signal bias, ionospheric error, which is a state in a state space, a mathematical vector space.

In this document, the correction that represents an error element is generically termed SSR. For example, the SBAS corrections may be termed SSR in this case. They shall be distinguished from RTCM SSR which is an international format standard developed by RTCM for the dissemination of specific SSR information parameters. The SSR correction shall also include integrity information for users.

The satellite clock correction can be also termed as the “fast correction”; and the satellite orbit correction can be also termed as the “long-term correction”; see 7.5.2 a) and b).

RTCM Standard 10403.3 supports DGNSS correction data; and RTCM is also developing a standard to support SSR information parameters. 3GPP LPP supports standard augmentation service as AGNSS in 3GPP release 8.

7.3 Precise augmentation service

This service shall adopt and provide one or more services from Table 3 in the service area defined in 6.3.

Table 3 — Precise positioning augmentation services and its transmitted correction data

Method	**Carrier-phased GNSS**	
Correction	**OSR**	**SSR**
Original technique	RTK — Pseudorange — Carrier-phase At a reference station	PPP — Satellite clock correction — Satellite orbit correction — Signal bias [a] — Integrity information [a]
Enhanced technique	Network RTK — Pseudorange — Carrier-phase At not only physical but also non-physical reference stations	PPP-RTK — Satellite clock correction — Satellite orbit correction — Signal bias (code) — Signal bias (carrier-phase) — Ionospheric correction — Tropospheric correction — Integrity information

[a] Optional.

The SSR correction such as PPP and PPP-RTK shall also include integrity information for users as shown in Table 3. In the case of adopting PPP-RTK using space link augmentation, the designer shall refer to ISO 18197.

Regarding the SSR corrections, the satellite clock correction can be also termed as the “fast correction”; and the satellite orbit correction can be also termed as the “long-term correction”; see 7.5.2, a) and b).

As comparison to standard augmentation service, the OSR includes not only pseudorange, but also carrier-phase; and the SSR includes not only ionospheric correction, but also tropospheric correction, for higher positioning accuracy.

Precise positioning augmentation services have characteristics in convergence time and CORS density as shown in Table 4. For detailed explanation, see References [55] to [58].

Table 4 — Precise positioning augmentation services and their characteristics

No.	**Positioning method**	**Convergence time**	**CORS density**	**Separation of CORS stations**		
				minimum	**typical**	**maximum**
1	RTK	Short[a]	Very dense	10 km	20 km	30 km
2	Network RTK	Short[a]	Dense	20 km	50 km	150 km
3	PPP	Long[a]	Sparse	500 km	1 000 km	3 000 km

[a] "Short" is categorized being from as one second to tens of seconds; "long" is categorized as being one minute to tens of minutes.

Table 4 *(continued)*

No.	Positioning method	Convergence time	CORS density	Separation of CORS stations		
				minimum	typical	maximum
4	PPP-RTK	Short[a]	Dense	20 km	50 km	150 km

[a] "Short" is categorized being from as one second to tens of seconds; "long" is categorized as being one minute to tens of minutes.

3GPP LPP also supports RTK, Network RTK, PPP in 3GPP release 15, and will support PPP-RTK in 3GPP release 16.

In actual applications, cross-border data exchange is often needed. See Annex A regarding this issue.

7.4 Geodetic service

This service shall adopt and provide one or more post-processing services for geodetic level positioning in the service area defined in 6.3. Geodetic level positioning is centimetre-to-millimetre-accurate positioning.

This service shall also provide raw data of the CORS station as a service for geodetic level positioning in the service area defined in 6.3.

7.5 Performance factors

7.5.1 General

This subclause specifies performance factors on the GNSS positioning augmentation centres. The system shall be designed to produce accurate outputs considering the factors specified in 7.5.2 to 7.5.4. Regarding transmission of augmentation data, see Annex C.

7.5.2 Communicable correction factors

The software shall correct the following factors depending on the required accuracy.

a) Satellite clock correction

   In case of using an optimal filter to induce this correction, it may be termed as "fast correction", because its application helps to minimize the fast-changing positioning errors resulting from temporal errors in satellite clocks.

b) Satellite orbit correction

   In case of using an optimal filter to induce this correction, it may be termed as "long-term correction", because it can be applied at a lower frequency and still have considerable effect to minimize the slowly changing positioning errors associated with satellite orbits.

c) Signal bias (code)

The software shall additionally output the following factors, when the designer selects positioning with ambiguity resolution.

d) Signal bias (carrier-phase)

The software shall distribute the following factors, when the designer selects PPP-RTK positioning.

e) Ionospheric correction

f) Tropospheric correction

In the case of PPP that is described in 7.3, the item d), e) and f) are optional.

Regarding transmission of augmentation data, see Annex B.

7.5.3 Receiver-dedicated correction factors

The software shall estimate the following factors, depending on the required accuracy.

a) Receiver clock error

b) Receiver antenna phase centre offset

c) Carrier-phase integer ambiguity

d) Receiver measurement noise

e) Multipath propagation caused by the environments

In this clause, the receiver is used in CORS that inputs to observation data to positioning augmentation centres. The environment of the receiver is mainly radio signal environment around an antenna of the receiver.

The specification of this clause is optional by the designer.

7.5.4 Other correction factors

The software shall store, estimate and correct the following parameters. These parameters are used for the improvement of positioning accuracies. They apply observation data which are inputted from CORS.

In each satellite, there are the following factors:

a) Satellite antenna phase centre offset

b) Satellite antenna phase centre variation

c) Satellite attitude and carrier-phase wind-up effect

In each constellation, there is the following factor.

d) Inter-system bias

Environment factors are the following.

e) Earth tide

f) Ocean tide

g) Crustal movement

h) Relativity effect

This clause is an optional specification that the designer can choose.

7.6 Integrity information

The designer shall design that the GNSS positioning augmentation centres provide integrity information to users as a), or both a) and b).

a) Alert flag

b) User range error (URE) including its components or differential quantities

This clause is an optional specification that the designer can choose.

NOTE RTCM specifies user range accuracy (URA). This is alias of URE. See RTCM Standard 10403. 3 or later.

8 Requirements for verification

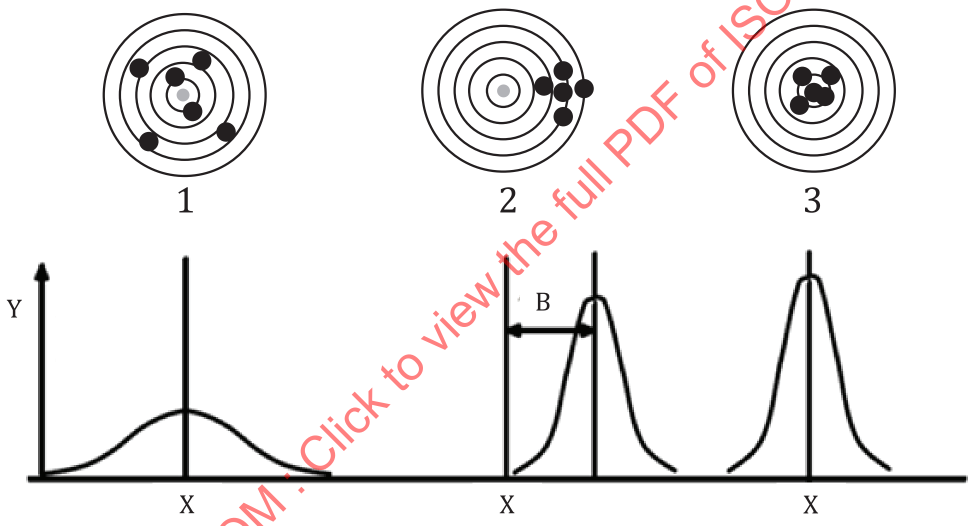
8.1 General

This clause specifies minimum requirements for verification on the GNSS positioning augmentation centre.

Regarding positional reference for precise navigation, see Annex D.

8.2 Distinction of accuracy and precision

The administrator shall use the definitions in Clause 3 of this document about accuracy and precision. The relation of accuracy (3.2.1) and precision (3.2.2) is shown in Figure 3.



Key

X true value of position

Y probability

B bias

1 low precision
low accuracy

2 high precision
low accuracy

3 high precision
high accuracy

Figure 3 — Relationship of accuracy and precision

This operation identifies error bias and error variability. Causes for bias error and the cause for variability error are different. Therefore, the administrator can investigate the cause of errors and improve the performance of positioning augmentation.

8.3 Verification

8.3.1 Principle

The administrator shall evaluate and verify positioning result the following quality control statistics in three-dimensional terms.

a) Standard deviation (precision)

b) Bias

c) RMSE (accuracy)

Among these three values, only two values are independent. They shall be evaluated and verified to clarify and represent the following three characteristics:

— repeatability of the positioning measurement system;

— systematic error of the positioning measurement system;

— overall error of the positioning measurement system.

Regarding supplemental information for approaches to evaluate positioning quality, see Annex F.

8.3.2 Horizontal

The administrator shall evaluate and verify positioning result as the following quality control statistics in two-dimensional horizontal terms.

a) Standard deviation (precision)

b) Bias

c) RMSE (accuracy)

8.3.3 Vertical

The administrator shall evaluate and verify positioning result as the following quality control statistics in one-dimensional vertical or altitude terms.

a) Standard deviation (precision)

b) Bias

c) RMSE (accuracy)

8.4 Calibration

The administrator shall calibrate the positioning augmentation system according to ISO 19161-1.

In particular, the methods of determining positioning in an ITRS realization shall be in accordance with ISO 19161-1:2020, Annex A.

8.5 Evaluation period

The administrator shall evaluate the data for the following periods:

a) every second in 24 hours;

b) at least two days every week over a one-year period.

This specification is based on the following reasons:

— every second for GNSS epoch time;

— 24 hours for diurnal variation;

— at least two days for diurnal check with arbitrary start point;

— every week for variation depending on satellite alignment period;

— one-year period for annual and seasonal variation.

8.6 Convergence time

The administrator shall evaluate the convergence time until obtaining the positioning result.

8.7 Quality control items

The administrator shall describe and quantify the positioning augmentation system as follows.

a) How the coordinates of the reference stations are computed.

b) When the coordinates values of the reference stations are computed.

It is not mandatory to publish coordinates values of the reference stations.

9 Requirements for maintenance

9.1 General

This clause specifies minimum requirements for maintenance on GNSS positioning augmentation centre.

9.2 Continuous performance monitor

The administrator shall monitor continuously the items specified in 8.3 and 8.6.

9.3 Cyber security

The administrator should measure cyber security including radio-frequency interference, as specified in ISO/IEC 27001.

The administrator should also establish, implement, maintain and improve the centre system for jamming, spoofing and meaconing against the CORS stations if there is no impact to the user due to possible cyber intrusion or if cyber attack is exceedingly unlikely.

Regarding meaconing in radionavigation, see Annex E.

9.4 User service

The administrator shall inform users of the GNSS positioning augmentation service about the following:

a) publication of the necessary information specified in Clauses 6, 7, 8 and Annex D to users who need it;

b) responding to users who require support by answering questions about system performance and operational statistics as described in Clauses 6, 7, 8 and Annex D.

Annex A
(informative)

Cross-border data exchange

The services of this document are designed so that homogeneous augmented positioning performance can be realized throughout different countries. Relying solely on the reference stations of individual countries, the accuracy and reliability of the position services would degrade towards the country borders due to missing external geometrical information.

The cooperation of neighbouring countries is inevitable in reaching this purpose. To overcome these degradations, it is expected to see the bilateral cross-border exchange of raw GNSS measurements of reference stations in order to extend the homogeneous service coverage areas to the borders. This cross-border data exchange would help to achieve the objective of homogenous positioning performance in each country.

The purpose of this annex is to draw the attention to networking stations, enabling them to select appropriate exchange data contents, data formats and transport protocols.

The RTCM standards should be used for cross-border data exchange.

Annex B
(informative)

GNSS constellations and systems

a) Global constellations
   - GPS: Global Positioning System (U.S.A.)
   - GLONASS: GLObal Navigation Satellite System (Russian Federation)
   - Galileo (EU)
   - BDS: BeiDou Navigation Satellite System (China)

b) Regional constellations
   - QZSS: Quasi-Zenith Satellite System (Japan)
   - NavIC: Navigation with Indian Constellation (India)

c) SBAS: satellite-based augmentation system
   - WAAS: Wide Area Augmentation System (U.S.A.)
   - MTSAT-based Augmentation System (Japan)
   - EGNOS: European Geostationary Navigation Overlay Service (EU)
   - GAGAN: GPS-Aided GEO Augmented Navigation (India)
   - SDCM: System for Differential Corrections and Monitoring (Russian Federation)
   - BDSBAS: BeiDou Satellite Based Augmentation System (China)

d) GBAS: ground-based augmentation system
   - LAAS: Local Area Augmentation System (U.S.A.)
   - Russian GBAS (Russian Federation)
   - GBAS in airport (many countries)

The following GNSS augmentation systems are currently in the planning/design/implementation stages, but have not achieved initial operational capability (IOC):

- Australian SBAS (Australia) (this is already a test-bed system)
- SouthPAN: Southern Positioning Augmentation Network (Australia and New Zeeland)
- KASS: Korea Augmentation Satellite System (Republic of Korea)
- KPS: Korean Positioning System (Republic of Korea)

Annex C
(informative)

Transmission of augmentation data

C.1 Standard augmentation service

This term describes the industry-known recommended specification for the transmission of augmentation data using the internet or satellite L-band service.

— RTCM Standard 10403.x data message

— RTCM Standard 10410.1 NTRIP for the data transmission

— BINEX Format [66]

C.2 Precise augmentation services

This term describes the industry-known recommended specification for the transmission of augmentation data in the internet or satellite L-band service.

— RTCM Standard 10403.x data message

— RTCM Standard 10410.1 NTRIP for the data transmission

— BINEX Format [66]

C.3 Geodetic service

This term describes the industry-known recommended specification for the transmission of augmentation data transmission through the internet.

— RINEX file format

— HTTPS or FTPS protocol

Annex D
(informative)

Positional reference for precise navigation

D.1 General

Space-based automated mobility-equipped precise navigation is becoming popular. Precise navigation needs geodetic information. This annex provides positional reference for precise navigation which needs higher accuracy than the crustal movement in a respective graphical region.

The positioning reference should be defined to comply with the universe of discourse defined in Clause 6. The reference coordinate system is recommended to be adopted ITRS that is defined in ISO 19161-1. In addition, ITRS is not always the adopted reference coordinate system, according to Table 1 (type IV).

D.2 Terrestrial reference system

In this clause, the basis of positioning reference to choose types in Table 1 is described for users' convenience.

The terrestrial reference system is defined by origin, orientation, scale, and time evolution as follows.

a) Origin

The centre of mass being defined for the whole earth, including oceans and atmosphere.

b) Orientation

Initially given by the BIH orientation at 1984.0.

c) Scale

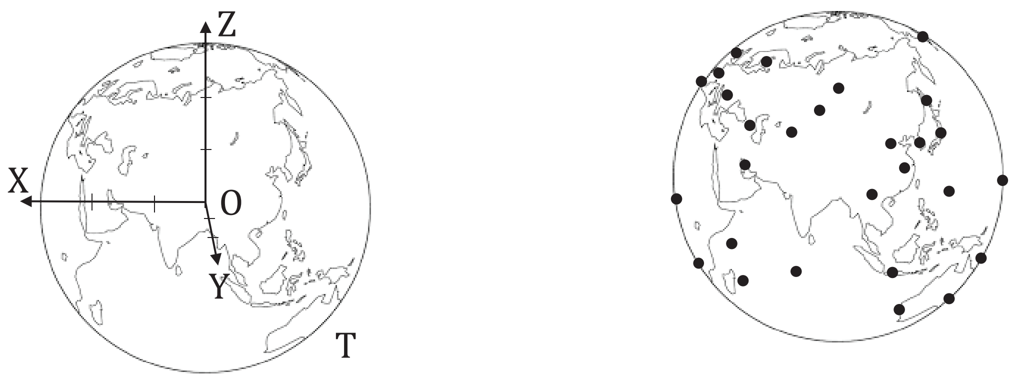
The unit of length is the metre (SI).

d) Time evolution

The time evolution of the orientation is ensured by using a no-net-rotation condition with regard to horizontal tectonic motions over the whole earth.

In Figure D.1, there are definition and realization. The definition are conceptual and mathematical specifications; the realization is a set of real facilities which make a terrestrial reference system operate for acural works. The realization consists of a real point list and their coordinates.

The realization of the terrestrial reference system shall be a set of authorized reference points shown as Figure D.1. Authorized reference points have regulatory ground based on international or national law that is organized by World Trade Organization (WTO), ICAO, IHO and respective nations.



a) Definition

b) Realization

Key

O	origin
X, Y and Z	orientation and scale
T	time evolution
●	reference station (example)

Figure D.1 — Definition and realization of terrestrial reference system

D.3 Global coordinate reference system

In this clause, the service type II (see 6.2) shall be applied to use a global coordinate reference system.

The global coordinate reference system shall be ITRF. It is recommended to apply the latest version.

NOTE WGS84 is widely used in space, aviation and maritime area with international treaties and agreements. It is also used in land-consumer sectors and the measurement of displacement, relative position and positional difference. WGS84 is often adopted as (or used in place of) ITRF in such applications.

D.4 National coordinate reference system

In this clause, the service type I (6.2) shall be applied.

A coordinate reference system may be associated with a realization of ITRS.

When a national coordinate reference system does not exist, it is recommended to apply Clause D.5.

D.5 Transformation of coordinate reference system and crustal movement

In this clause, the service type I (6.3) shall be applied.

The national coordinate reference system shall be transformed as specified in ISO 19161-1.

The coordinate transformation is represented by Formula (D.1).

$$\begin{pmatrix} X_N \\ Y_N \\ Z_N \end{pmatrix} = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + \begin{pmatrix} 1+D & -R_z & R_y \\ R_z & 1+D & -R_x \\ -R_y & R_x & 1+D \end{pmatrix} \begin{pmatrix} X_G \\ Y_G \\ Z_G \end{pmatrix} + \begin{pmatrix} S_x \\ S_y \\ S_z \end{pmatrix} \tag{D.1}$$