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Space systems — Space-based services for a high accuracy positioning system with safety requirements

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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).

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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

This document is a technical specification of space-based services. Space systems provide a huge merit for the society and economy 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 industry worldwide in the future.

Space systems are utilized in the application of other areas. Therefore, this document has harmonized the content in the GNSS (global navigation satellite system) relevant area as shown in Figure 1.

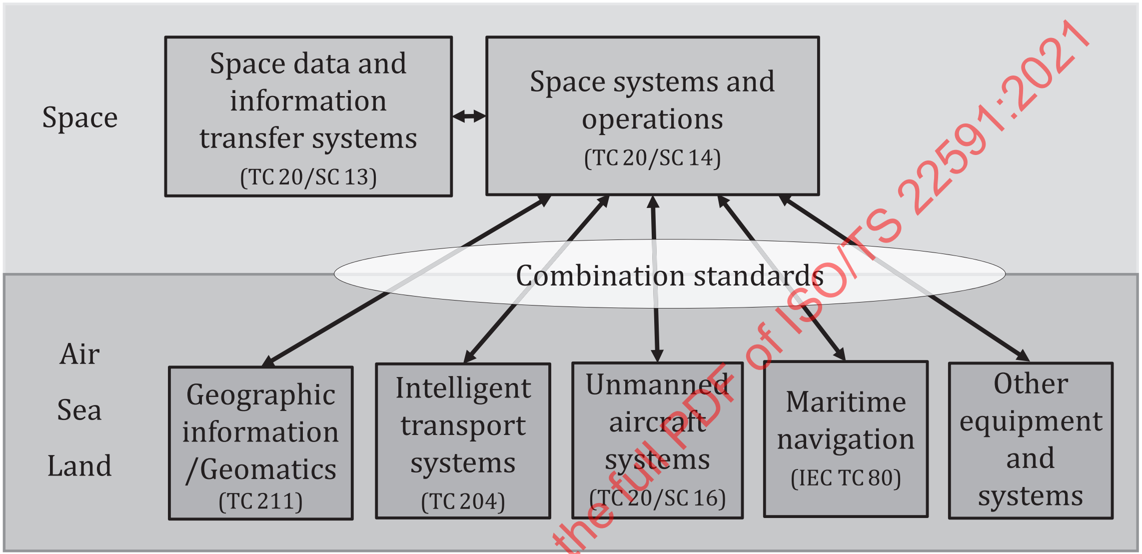

Figure 1 — Standardization of space-based services: GNSS relevant area

Space systems often become the last hope for people in harsh weather conditions to ensure the safety of life. This document is intended to ensure the safety with the power of space systems.

The operation of moving machines under such harsh conditions is difficult and unsafe for machine operators. For example, snow removal work with a snowplough is very difficult and unsafe for non-skilled workers. It is necessary to have experience and skills to operate the vehicle near the edges and features of a course. Because it takes a long period of training time to learn the operation skills for manoeuvring a work vehicle, it is becoming a serious problem in areas with heavy snow to secure the highly skilled workers who operate these vehicles and to maintain a continuous plan for subsequent replacement due to the retirement of skilled workers.

The purpose of this document is to mainly determine the safety requirements for a space-based high accuracy positioning system by which vehicles can be operated safely even in low visibility conditions with less experienced operators having minimum experience and skills.

This document refers to some general systems such as agricultural machines, road cleaning machines or construction machines which require positioning accuracy. It applies to general works such as staying the course, docking, and unloading works.

In general, it is difficult and dangerous to operate machines in low visibility due to harsh optical conditions. In such situations, the machine's positioning system requires a high degree of accuracy. This document considers the following two distinctive features commonly observed in the high accuracy positioning applications requiring safety.

— Generally speaking, a rover needs to be operated in situations where image sensors (cameras or LiDARs or both) cannot be used and the risk of accidents becomes higher.

— In addition, a machine needs to be operated in close proximity to various kinds of obstacles such as signals, signs and guide-rails on boundary lines because of its purpose. This is the main reason for the necessity of having skilled operators.

Ultimately, this document aims to help system design by which a rover can be operated safely even in low visibility situations with less experienced operators to contribute to improving the quality of life through the space-based service.

Space systems — Space-based services for a high accuracy positioning system with safety requirements

1 Scope

This document provides requirements and recommendation for space-based systems that, using satellite radionavigation services, provide high accuracy positioning of rovers. It is particularly intended for rovers whose operation requires meeting specific safety requirements, including in situations of low visibility. This document also provides methods to verify the system requirements, as well as complementary information on particular applications (Annex A), mobile mapping systems (Annex B) and augmented positioning (Annexes C and D).

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 18197:2015, *Space systems — Space based services requirements for centimetre class positioning*

3 Terms and definitions

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

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

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

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

3.1
satellite radionavigation
satellite radiodetermination (3.2) used for *radionavigation* (3.3)

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

3.2
satellite radiodetermination
radiodetermination (3.4) which makes use of a satellite system

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

3.3
radionavigation
radiodetermination (3.4) used for the purpose of navigation, including obstruction warning

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

3.4
radiodetermination
determination of the position, velocity 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]

3.5
safety
state where an acceptable level of *risk* (3.6) is not exceeded

Note 1 to entry: Risk relates to:

— fatality,

— injury or occupational illness,

— damage to hardware or facilities,

— damage to an element of an interfacing manned system,

— the main functions of a system itself,

— pollution of the environment, atmosphere or outer space, and

— damage to public or private property.

[SOURCE: ISO 10795:2019, 3.210, modified — Note 1 to entry has been generalized for activities on planets or moons.]

3.6
risk
undesirable situation or circumstance that has both a likelihood of occurring and a potentially negative consequence on a project

Note 1 to entry: Risks arise from uncertainty due to a lack of predictability or control of events. Risks are inherent to any project and can arise at any time during the project life cycle; reducing these uncertainties reduces the risk.

[SOURCE: ISO 17666:2016, 3.1.12]

3.7
accuracy
closeness of agreement between a test result or measurement result and the true value

Note 1 to entry: In practice, the accepted reference value is substituted for the true value.

Note 2 to entry: The term “accuracy”, when applied to a set of test or measurement results, involves a combination of random components and a common systematic error or bias component.

Note 3 to entry: Accuracy refers to a combination of bias and precision.

[SOURCE: ISO 3534-2:2006, 3.3.1, modified — In note 3 to entry, “trueness” has been changed to “bias”.]

3.8
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, DOT-VNTSC-OST-R-15-01, A.1.10]

3.9
dead reckoning
method to obtain a vehicle position by using a compass or inertial measurement or both, and which can be connected with vehicle sensors which record a forward distance and steering direction

3.10
integrated positioning
positioning incorporating two or more positioning technologies

[SOURCE: ISO 19116:2019, 3.14, modified — "system" has been removed from the term and the definition; note 1 to entry has been removed.]

3.11
mountainous district
district where necessary satellites are not visible for positioning regularly due to being blocked by mountains

4 Abbreviated terms

DGNSS	differential GNSS
GNSS	global navigation satellite system
HDOP	horizontal dilution of precision
IMU	inertial measurement unit
LiDAR	light detection and ranging
MMS	mobile mapping system
RFID	radio frequency identification
RMS	root mean square

5 Service system and risks

5.1 Service system

The high accuracy positioning system for rovers is intended to serve general works such as staying the course, docking, and unloading, as illustrated in Figure 2.

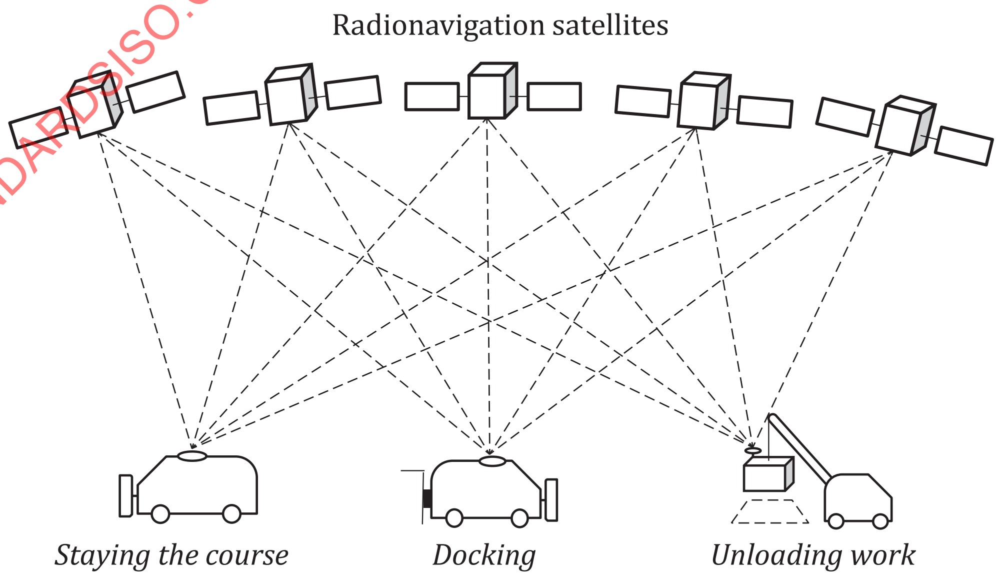

Figure 2 — System overview: work examples

To establish this service system, it is necessary to clarify the target of the rover works. In this document, the works have been classified into 4 categories by target works and object sizes as shown in Table 1. The service system varies depending on the category of the target work. The object size is the size that should be recognized by a precise positioning rover to execute the target work.

Table 1 — Categorization and target work

Work category	Example of target work	Guide of object size in RMS
1	— Keep course edge or side line clear from dirt or snow — Keep docking position between the vehicle and the supply station such as power, fuel	0,1 m to 0,25 m
2	— Keep side strip or side path clear	0,25 m to 0,5 m
3	— Keep course width or flatness roughly — Spread usable area of intersection	0,5 m to 1 m
4	— Stay along the wide course — Keep landing area	Over 1 m

ISO 18197 applies to the work category 1. ISO 18197:2015, 5.4.1 also specifies metre class positioning, which applies to the work categories 2 to 4.

5.2 Risks

The following risks are inherent to a rover making use of the high-accuracy positioning system:

a) collision to obstacles;

b) dropping from course edge;

c) damage through the works;

d) collision to other vehicles.

In order to manage these risks, Clause 6 specifies safety requirements.

6 Rover safety requirements

6.1 General

In order to establish general principles for a high accuracy positioning of rovers, it is important to clarify the related rover safety requirements and recommendations. Seven rover safety provisions are identified in 6.2 to 6.8. Depending on which safety provisions need be met, the positioning system can vary. The specific system specifications and their verification are covered in the subsequent subclauses as specified in Table 2.

6.2 Usage of accurate map data (safety provision 1)

The high accuracy positioning rover shall use the accurate map data.

6.3 Indication of positioning quality (safety provision 2)

The high accuracy positioning rover shall check the positioning quality and shall be operated depending on the quality indication.

6.4 Collision avoidance to the obstacles on the course (safety provision 3)

The high accuracy positioning rover should give the alarm depending on the relative distance between the feature and the obstacles on the map.

6.5 Dropping avoidance from the course edge (safety provision 4)

The high accuracy positioning rover should give the alarm depending on the relative distance between the vehicle and the road edge on the map.

6.6 Damaging avoidance through the work (safety provision 5)

The high accuracy positioning rover should give the alarm by recognizing restricted area of work (e.g. snow-throwing).

6.7 Collision avoidance to other vehicles or pedestrians (safety provision 6)

The high accuracy positioning rover should give the alarm depending on the relative distance between the other vehicles or pedestrians by using proximity sensors.

6.8 Positioning supplement in GNSS unavailable area (safety provision 7)

The high accuracy positioning rover shall supplement the positioning by using supplemental sensors or V2V/V2X (vehicle to vehicle/vehicle to X) communications or both when GNSS signals and/or GNSS augmentation data are not available, for example in a mountainous district.

Table 2 — System specification and verification for safety

Safety provision	System specification	Verification	Provision level
1. Usage of accurate map data	7.2.1 Accuracy of map data	8.1.1 Verification of accuracy of map data	Requirement
2. Indication of positioning quality	7.3.4 Positioning quality	8.2.4 Verification of positioning quality	Requirement
3. Collision avoidance to the obstacles on the course	7.2.2 Human machine interface	-	Recommendation
4. Dropping avoidance from the course edge	7.2.2 Human machine interface	-	Recommendation
5. Damaging avoidance by discharge	7.2.2 Human machine interface	-	Recommendation
6. Collision avoidance to the other vehicle or pedestrians	7.2.2 Human machine interface	-	Recommendation
7. Positioning supplement in GNSS unavailable area	7.3.5 Usage of integrated positioning	8.2.5 Verification of usage of integrated positioning	Requirement

7 System specifications

7.1 General

The following system specifications are derived from the safety provisions:

— usage of highly accurate map;

— high accuracy positioning.

7.2 Requirements of usage of high accuracy map

7.2.1 Accuracy of map data

This specification is derived from safety provision 1. Depending on the work category and safety requirements, the accurate map data shall be prepared beforehand. The required accuracy is summarized in Table 3. Respective applications can specify their values of threshold to be applied based on this requirement.

Table 3 — Categorization of work and required accuracy of the map

Work category	Accuracy of map in RMS	Traditional scale (informative)
1	≤ 0,1 m	1:100
2	≤ 0,25 m	1:250
3	≤ 0,5 m	1:500
4	≤ 1 m	1:1 000

In addition, it shall be assured that the map data are up to date. It is effective to use MMS or equivalent for efficient data collection (See Annex B).

7.2.2 Human machine interface

Regarding human machine interface, 3 main features (vehicle position, peripheral environment, and positioning quality) shall be indicated. At the same time, the indication should not be a burden for the operator. The details of the indication should be decided by the designer depending on the work category and safety requirements. The required items of indication to be designed are as follows.

a) Rover position

The following items shall be designed.

1) Items to be indicated

Vehicle position and travel direction

2) Distance to course edge or obstacles

Method of expression

b) Peripheral environment

The following items shall be designed.

1) Items to be indicated

Course features, objects, discharge availability, etc

c) Positioning quality (safety provision 2)

Augmentation data receiving status, or integrity of positioning calculation, etc. which is mentioned in 6.3 shall be indicated.

The recommended items of indication to be designed are as follows.

d) Alarm of proximity to course features (safety provision 3)

Depending on the situation of the work target course, the necessity and the detail of the following function should be decided.

— When the vehicle gets closer to the course features or structures than threshold, the alarm to be given depending on the distance.

e) Alarm of dropping off from the course edge (safety provision 4)

Depending on the situation of the work target course, the necessity and the detail of the following function should be decided.

— When the distance to the course edge gets closer than threshold, the alarm to be given depending on the distance.

f) Alarm of work restriction (safety provision 5)

Depending on the situation of work target course, the necessity and the detail of the following function should be decided.

— The restricted area of discharge, and the current availability of work to be indicated.

g) Alarm of proximity to other vehicles or pedestrians (safety provision 6)

Depending on the situation of the work target, the necessity and the detail of the following function should be decided.

— When the distance to the other vehicles or pedestrians gets closer than threshold, the alarm to be given depending on the distance.

7.2.3 Maintenance of map data

The update period and method of map data updating shall be determined such that the accuracy of the map satisfies the requirement at the time of work.

7.3 Requirements of high accuracy positioning

7.3.1 Positioning accuracy

Depending on the work category of the target, the necessary accuracy should be determined. The required accuracy is summarized in Table 4. Respective applications can specify their values of threshold to be applied using this requirement.

Table 4 — Categorization of safety-critical work and required accuracy for positioning

Work category	Accuracy for positioning in RMS (Horizontal error)
1	≤ 0,1 m
2	≤ 0,25 m
3	≤ 0,5 m
4	≤ 1 m

Annex C specifies effective ways to achieve positioning accuracy. An augmentation service shall be chosen to enable required accuracy.

ISO 18197 applies to the work category 1. ISO 18197:2015, 5.4.1 also specifies metre class positioning, which applies to the work categories 2 to 4.

7.3.2 Positioning method

The positioning method shall be highly accurate positioning by using augmented GNSS positioning (see Annex C) and an external sensor such as IMU, radar, LiDAR, video camera.

7.3.3 Reception of augmentation data

According to the positioning method, receiving augmentation data is necessary. The system shall be able to receive the augmentation data.

Annex D specifies effective ways to receive the augmentation data.

7.3.4 Positioning quality (safety provision 2)

The positioning quality shall be calculated and indicated. The items to be considered are as follows:

— number of satellites available;

— HDOP;

— positioning status, e.g. fix / float / standalone / DGNSS / dead reckoning;

— guide of current positioning accuracy;

— receiving status of augmentation data;

— integrity of positioning calculation by using the latest techniques.

7.3.5 Usage of integrated positioning (safety provision 7)

This relates to safety provision 7. In case of GNSS blocking, if the target area includes the GNSS unavailable area such as a mountainous district, the system shall have integrated positioning method, which is the positioning system using supplemental sensors such as IMU, odometer, geomagnetic sensor, or using V2V/V2X communications data.

7.3.6 Real-time property

The positioning calculation speed shall be considered by putting importance on the real-time property from the viewpoint of safety. The positioning update rate shall be as quick as possible depending on the operation speed suitable to the target work.

Generally, the system error budget is described as follows.

$$e_s = e_p + e_m + v\, t_p$$

where

e_s is the system error [m];

e_p is the positioning error [m];

e_m is the map error [m];

v is the operational speed to the target [m/s];

t_p is the position update rate [s].

The positioning update rate should be decided so that the system error does not exceed the target object's size. The operational speed to the target is the relative speed of the rover to the target. It may become small, if the vehicle doesn't approach the target.

7.3.7 Improvement of availability

The availability of positioning in target area should be studied in advance. In unavailable area, improvement method should be considered as follows in addition to integrated positioning (see 7.3.5):

— error cancelling by fixed RFID tag information;

— error cancelling by detection of road edge using proximity sensors, stereo cameras, etc.

8 Verification

8.1 Verification of highly accurate map

8.1.1 Accuracy of map data

According to ISO 19157, a geographic data set has 21 quality elements, which are organized into six categories: completeness, thematic accuracy, logical consistency, temporal quality, positional accuracy, and usability. Regarding the positional accuracy, ISO 19157 provides the following three elements:

— absolute or external accuracy: closeness of reported coordinate values to values accepted as or being true;

— relative or internal accuracy: closeness of the relative positions of features in a data set to their respective relative positions accepted as or being true;

— gridded data positional accuracy: closeness of gridded data spatial position values to values accepted as or being true.

The map data of work target area shall be verified in absolute accuracy, because the map data are a base on which GNSS (absolute) positioning is calculated. The reference points shall be plural points and surveyed based on the area's certified method. The verification criteria follow the description in Clause 7.

The map data verification shall be implemented periodically; and this is regarded as a calibration. The frequency of verification should depend on the use cases.

For an effective way of map creation or evaluation, MMS can be one of solutions (see Annex B).

8.1.2 Human machine interface

The human machine interface shall be verified according to the following items:

— whether the system has the vehicle position indication;

— whether the system has the peripheral environment indication;

— whether the system has positioning quality indication.

8.1.3 Maintenance of map data

The map data shall be verified according to the following items:

— whether the system's manual includes the period of map updating;

— whether the system's manual includes the method of map updating.

8.2 Verification of highly accurate positioning

8.2.1 Positioning accuracy

Based on ISO 18197:2015, Clause 7, the positioning data shall be verified.

a) Evaluation plan

The following items to be decided.

Evaluation procedure

Verification of fitting rate should be chosen. The criteria shall follow 7.3.1.

— Evaluation items

Accuracy evaluation of positioning result shall be chosen.

— Data

Real-time output data shall be chosen.

b) Verification conditions

The following items to be decided.

— Period

The period of evaluation should be decided according to the use cases.

— Place

Same environment shall be chosen according to the use cases.

— Reference points

Plural reference points shall be decided in the target area.

— Positioning objects

For approaching the real operating environment, mobile objects should be chosen.

c) Evaluation criteria

The criteria shall follow 7.3.1.

d) Verification methods

The "Procedure of evaluation of the positioning accuracy of the reference points along the travelling route" should be chosen from the perspective of real operating environment.

Select the reference points in the neighbourhood of the vehicle's travelling route. The positioning result of these reference points can be obtained by the surveying method.

Calculate the positioning result of these reference points in the time zone of the vehicle's travelling by the method of interest.

Evaluate the method of interest by comparing the positioning result by the method of interest with the positioning result by the surveying method, where the latter can be regarded as correct.

8.2.2 Positioning method

The positioning method shall be verified according to the following item: whether the positioning method is applied with appropriately accurate positioning.

8.2.3 Reception of augmentation data

The reception of augmentation data shall be verified according to the following item: whether the augmentation data are applicable to the positioning method.

8.2.4 Positioning quality

The positioning quality shall be verified according to the following item: whether the positioning quality information is calculated as correctly as possible, and indicated on the system.

8.2.5 Usage of integrated positioning

The usage of integrated positioning shall be verified according to the following item: whether the integrated positioning is applied to the system when the target area includes the GNSS unavailable area.

8.2.6 Real-time property

The real-time property shall be verified according to the following item: whether the positioning update rate is sufficient comparing to the operation speed to the target.

Annex A
(Informative)

Examples of application

A.1 Snowplough

A.1.1 System configuration

A.1.1.1 General

In this subclause, an example system configuration which belongs to the work category 1 and fulfils safety provisions 1 to 7 is shown in the snowplough case. See Figure A.1.

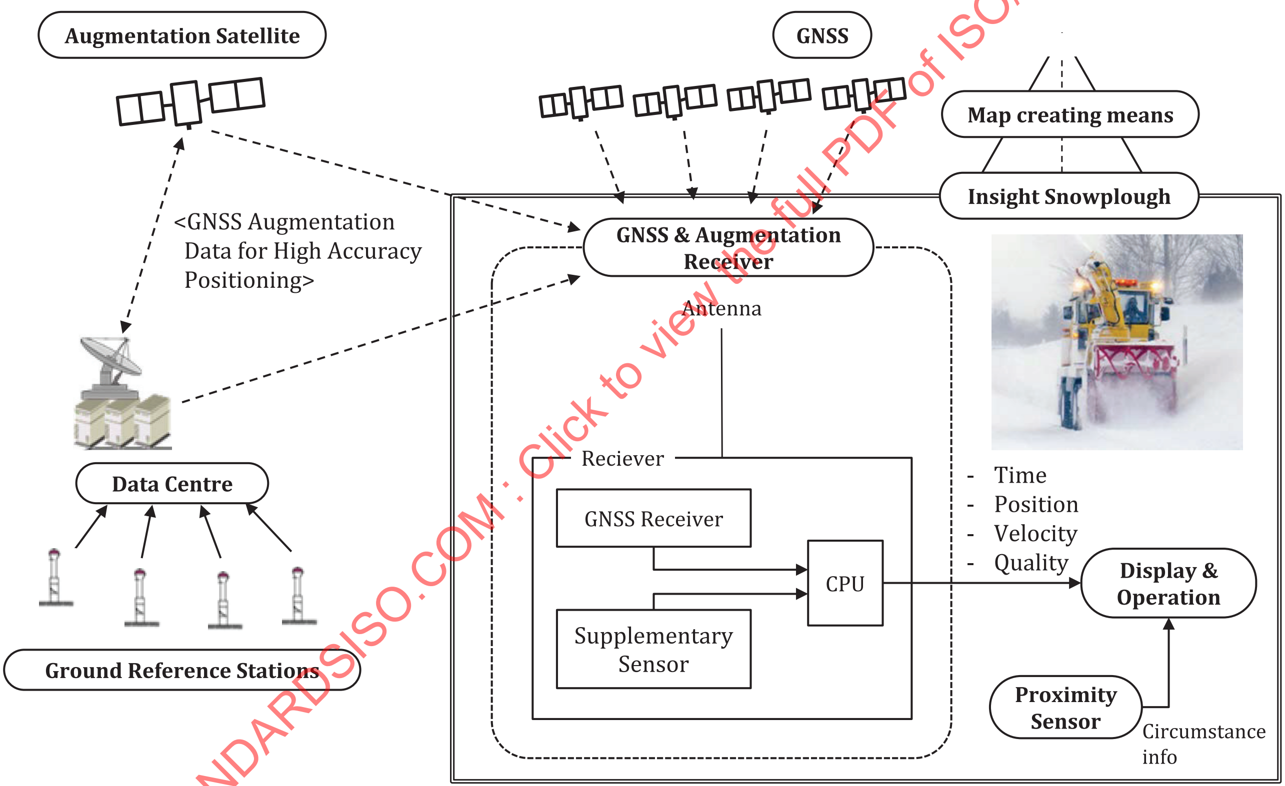

Figure A.1 — An example of system configuration

A.1.1.2 Points of this system configuration example

a) Before snow season, the topographic data (image or laser point cloud) of the target road is collected by using map creating means, and the accurate map is created (safety provision 1).

b) The snowplough is equipped with a terminal which has GNSS receiving functions; and the terminal implements accurate positioning by using both GNSS data and augmentation data for highly accurate positioning.

c) In order to require stable receiving of the augmentation data in mountainous district, the augmentation data are distributed via satellite, which is “augmentation satellite”.

d) In case of unstable GNSS situation (tunnel, underpass or mountainous district), supplement sensors are used (safety provision 7).

e) The snowplough is equipped with proximity sensors to monitor the peripheral environment.

f) The snowplough is equipped with an information indication means which indicates and operates the system. The information indication means indicates the current position, positioning quality or the peripheral objects around the snowplough (safety provision 2).

g) The system includes an augmentation centre which gathers the data of ground reference points and generates the augmentation data. The augmentation data are uplinked to the augmentation satellite for the broadcast or transmission to each snowplough.

A.1.2 Operation overview

A.1.2.1 General

In this example, the positioning update rage is 1 Hz, regarding 7.3.6 on the verification of real-time property.

A.1.2.2 Basic operation

The system starts at GNSS satellites available area adequately. Before moving the snowplough, the operator checks the indicator, waits for good GNSS positioning quality, and then, moves the snowplough checking the self-position.

In case that the GNSS quality falls when moving, the snowplough is stopped or moved to the GNSS available area by the operator, waiting for the GNSS quality to get good positioning. After checking the good positioning, the snowplough is moved back to the work.

A.1.2.3 Indication of the self-position

The system indicates the snowplough's position. Especially, it indicates the snowplough's edge of the body, such as tires, bumper, blade or shovel. The operator operates the snowplough by checking its edge so as not to collide road features or drop from the road (safety provision 2).

A.1.2.4 Positioning quality indication

Positioning quality is notified (safety provision 2). The operator operates the snowplough as specified in A.1.2.2 by checking the indication.

A.1.2.5 Indication of distance to road edges or features

The distance to road edges or features is indicated by using the current position data of the snowplough and each road edge or feature around the snowplough (safety provision 3 and 4).

A.1.2.6 Indication of snow-throwing availability

Current self-position data and the restricted area of snow-throwing are compared; and the alarm is given by the system when entering the restricted area (safety provision 5).

A.1.2.7 Collision avoidance by using proximity sensors

The system always monitors the distance with the objects around the snowplough. In case the distance becomes closer than the threshold, the alarm is given by the system (safety provision 6).

A.1.3 Example of human machine interface

An example of human machine interface to realize the above operation image is shown in Figure A.2. Regarding the map data, 3D map is desirable.

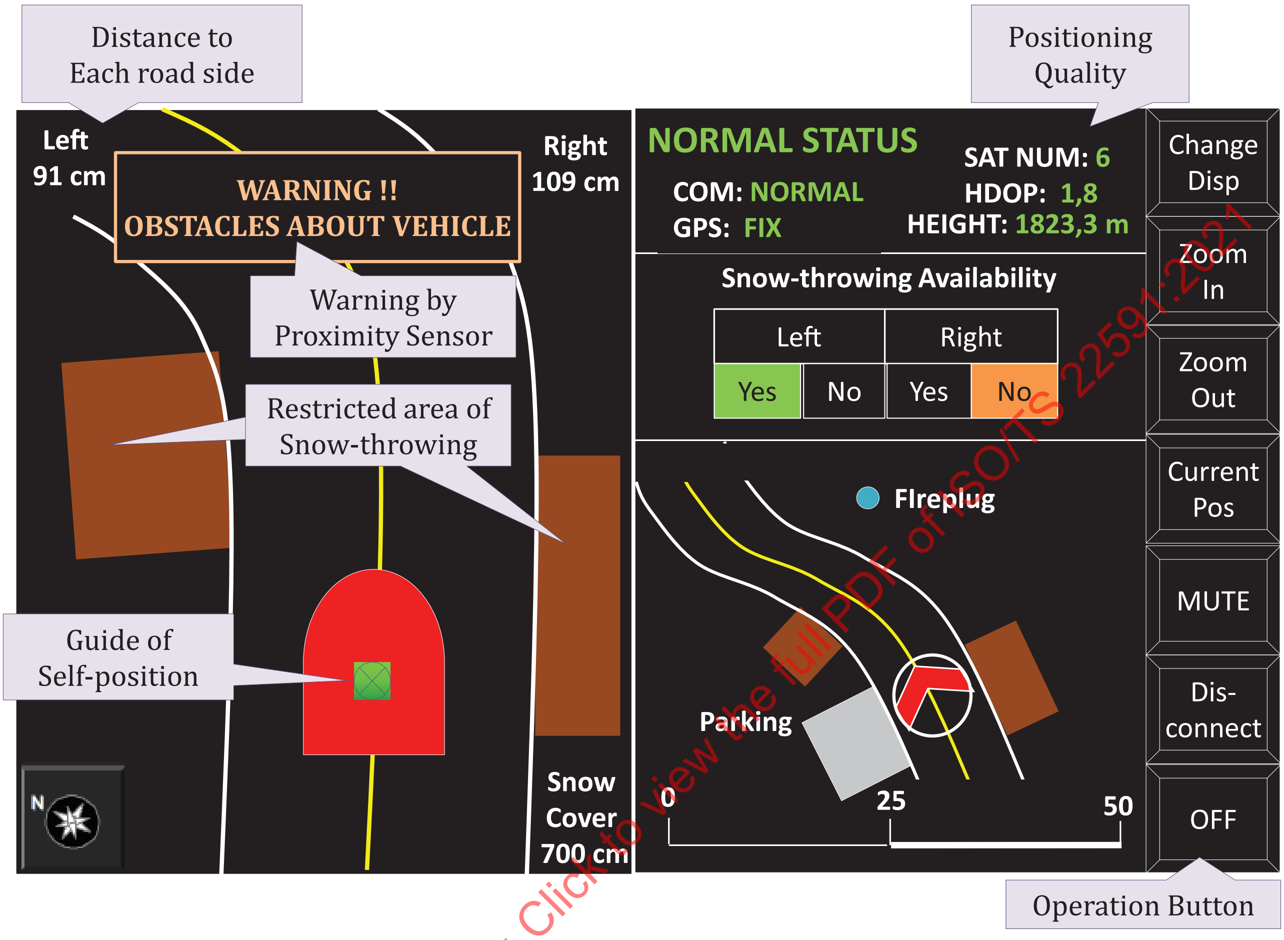

Figure A.2 — An example of human machine interface

A.2 Tractor

A.2.1 System configuration

A.2.1.1 General

In this subclause, an example system configuration which belongs to the work category 1-2 and fulfils safety provisions 1 to 7 is shown in the tractor case.

A.2.1.2 Points of this system configuration example

a) The GNSS guidance system displays the current position of the tractor on the monitor screen based on the positioning results by using both GNSS data and augmentation data and guides the tractor's travel route according to the farm work. It can be regarded as "car navigation for farm work". By running the tractor according to the guidance, farm work such as puddling, fertilization, sowing, repelling insect, tillage, pasture related work can be realized with accurate route. The target work is shown in Table A.1.

Table A.1 — Categorization and target of tractor work

Work category	Example of target work
1	— sowing and replanting — digging — putting a sheet — cultivating and weeding — tillage — reaping the grass — flipping the grass
2	— puddling — spray fertilizer, soil modification material, compost — repelling insect — night work

b) The tractor uses the latest electronic map (safety provision 1).

c) The tractor is equipped with a terminal which has functions of receiving both GNSS data and augmentation data. The latter data are obtained via satellite line or via ground line. The user selects the line according to the field conditions. It has been pointed out that there are places where it is difficult to receive GNSS signals such as windbreak forests. Measures for when GNSS signals cannot be used are often not implemented, however, because farmland where GNSS guidance is introduced has good visibility. As countermeasures, using the camera images of distant landscapes and ridge grooves as a reference is being considered in addition to the use of gyros and accelerometers (safety provision 7).

A.2.2 Operation overview

A.2.2.1 Basic operation

First, a field outline is registered; and then a tractor travel route is generated. This work can be omitted if there are previous data. When working with a plurality of tractors, levelling is performed beforehand in some cases. In the case of an independent work, the work can be started after the travel route is generated.

A.2.2.2 Indication of the self-position

The system indicates the tractor's position on the monitor screen. It also indicates tractor's heading direction, speed, the area where work has been done, etc. (safety provision 2).

A.2.2.3 Positioning quality Indication

The number of received satellites and positioning status are displayed on the monitor screen, indicating the degree of reliability of the information (safety provision 2).

A.2.2.4 Indication of distance to road edges or features

The guideline and the deviation from the guideline are displayed on the monitor screen. Dangerous spots (dents, mud, stones, etc.) on the field can be recorded as information during the previous operation and can be displayed during the next operation (safety provision 3 and 4).

A.2.2.5 Indication of work availability

The satellite image is superimposed on the field screen; and the current position of the tractor is displayed. The area where work has been done and the area to be worked on are color-coded; and an alarm is given by the system when the heading direction is shifted to the left or right or when the vehicle moves out of the field (safety provision 5).

A.2.2.6 Collision avoidance by using proximity sensors

At present, most tractors are based on the operator's visual confirmation of the surroundings and collision avoidance. Furthermore, high-end systems are equipped with laser sensors and so on to detect obstacles and activate alarms (safety provision 6).

A.2.3 Example of human machine interface

The functions corresponding to the work are clearly displayed on the large monitor screen so that the operator can easily understand the condition of the tractor and the work. The operator can also scroll the screen and enlarge or reduce the content.

A.3 Bulldozer

A.3.1 System configuration

A.3.1.1 General

In this subclause, an example system configuration which belongs to the work category 1 and fulfils safety provisions 1 to 7 is shown in the bulldozer case.

A.3.1.2 Points of this system configuration example

a) Machine guidance / machine control is to measure the position information of the construction machine such as a bulldozer, using a position measuring device and provide the operator with the difference between the design data of the construction site and the local ground data. Or based on the difference, it automatically controls height and gradient. The difference from the design is displayed on the operator screen; and the construction is performed while checking the construction status.

b) In order to maintain the consistency between the reference map and the measurement results, it is recommended that the fixed points in the site be coordinated, and buckets and blades be applied to check the accuracy on a daily basis (safety provision 1).

c) The bulldozer is equipped with a terminal which has functions of receiving both GNSS data and augmentation data. The latter data are obtained via satellite line or via ground line. The user selects the line according to the field conditions.

d) This system is applied after confirming that there is no wireless communication failure and that the site is not a narrow part or mountainous district where satellite acquisition is difficult. (safety provision 7).

A.3.2 Operation overview

A.3.2.1 Basic operation

Attach equipment such as valves, sensors, and control boxes to the bulldozer to control the bulldozer blade. As a calibration work, measure the width of the bottom edge of the bulldozer blade and that of the bulldozer blade from the centre of the GNSS antenna, and input the model name, type of sensors, dimensions, etc. to the work application. Work is started after confirming the positioning accuracy of the bulldozer blade.