5 Satellite Positioning

5-1 Development Status of the World's GNSSs and the Trend of the Satellite Positioning Utilization

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In 2010, some Global Navigation Satellite Systems (GNSSs) has been constructing and there will be over 100 navigation satellites around the Earth. In particular, Asia longitude area will be the most viewable area from the navigation satellites because of the GLONASS (GLObal NAvigation Satellite System), QZSS (quasi-zenith satellite system) and Compass / BeiDou-2 in next 10 years. This paper introduces the activities of the each GNSSs and the trend of the Multi-GNSS utilizations.

Keywords
GNSS, QZS, Multi-GNSS Asia, Time transfer

1 Global Navigation Satellite System

Throughout the long history of navigational technology, people determined positioning based on the stars. However, since stars are not always visible, safe navigation was only possible under clear skies. Satellite positioning enables positioning to be determined by deploying a man-made star that transmits radio waves rather than star light, regardless of weather conditions. Since these radio waves are transmitted at a predetermined speed (speed of light) without relying on a coordinate system, the distance between the transmitter and observer can be determined by measuring the propagation time of the signals. In principle, if one can get positions more than 3 transmission stations, the position of the observer can be determined by the trilateration provided that the time on both the signal transmission side and receiving side are accurately synchronized. In the actual satellite positioning, a minimum of 4 satellites are required to determine the 4 parameters of longitude, latitude, height and time of receivers. In addition, attention must be paid in order to ensure that ionosphere, troposphere, moisture delay and multipath is also included in the observed pseudo-range. Furthermore, in order to secure 4 or more visible satellites anywhere above the world, it is necessary to revolve tens of satellites around the earth like the GPS. This type of system that enables satellite positioning around the world is referred to as the GNSS (Global Navigation Satellite System).

Although satellite positioning by GNSS was developed for military purposes such as GPS (Global Positioning System) and GLONASS (GLObal NAvigation Satellite System), this has recently made a large contribution to people around the world as a social infrastructure that acquires positional information anywhere. Independent systems such as the GNSS and RNSS (Regional Navigation Satellite System) are established in each country in the aim to provide stable service that is not affected by economic and emergency situations in other countries, and display national power.

The number of currently planned global GNSS and RNSS scheduled to be launched and the signal characteristics are shown below. The number of GNSS and systems to be constructed is predicted to increase over the next 10 year transition period. An outline of the QZSS, Japan's first navigation satellite system, where NICT is in charge of the time management system, will also be discussed below. Because the details of the signals include the information which is still in the planning stage, they will be changed.

1.1 GPS

Although 24 GPS satellites are required to provide services around the whole world, the current lifespan of satellites is 10 years or more and as of July 2010, there are 31 satellites in operation. All the Block-I satellites have been decommissioned and currently there are 11 Block-ⅡA satellites (equipped with 2 Rb clocks and 2 Cs clocks), 12 ⅡR (3 Rb clocks) satellites (7 Block-ⅡR-M satellites that transmit L2C signals) and one Block-ⅡF satellite that transmits L5 signals. In addition, the SA function (intentional degradation of the accuracy of civil signals) was cancelled from May, 2000, and it has been announced that this function will not be used in the future.

The Block-Ⅲ satellites that transmit L1C signals are scheduled to be launched after 2014 and all 24 satellites are scheduled to be in operation in fiscal 2021. Furthermore, Block-Ⅲ satellites are scheduled to have their anti-jam capability enhanced and search and rescue functions added. An outline of the civil signals for GPS is shown in Table 1[1]. BPSK (Binary Phase Shift Keying) is used as the modulation format for civil signals.

In addition, GPST (GPS time), the time scale of GPS, is synchronized within 10 ns of UTC (UNSO) and the coordinate system uses the World Geodetic System 1984 (WGS84) that defines the Earth-Centered, Earth-Fixed (ECEF) orthogonal coordinate system.

1.2 GLONASS

In Russia, the M Series which has a longer lifespan and complies with the second civil signals commenced operation from 2003, and as of October, 2010 (current), there are 23 M Series satellites in operation and it is possible that all 24 satellites will return to operation by the end of 2010. Furthermore, the smaller-/longer-life K Series with additional the third civil signals is planned from 2015. Currently, GLONASS and GPS are not operationally compatible since not only are the L band frequencies different, but also the modulation format for GLONASS is FDMA (Frequency-Division Multiple Access) and CDMA (Code Division Multiple Access) for GPS. However, in order to make the K Series compatible with GPS, the K Series will utilize CDMA. An outline of the civil signals for GLONASS is shown in Table 2.

Table 1 *Catalog of the GPS civil signals (BPSK: Binary Phase Shift Keying)*

Name	Center frequency [MHz]	Chip rate (Mcps)	Modulation scheme	GPS support	Feature
L1-C/A	1575.42	1.023	BPSK(1)		Most widely used civil signal
L2C	1227.60	1.023	BPSK(1)	supported from 2005	The second civil signal
L5	1176.45	10.23	BPSK(10)	supported from 2010	The third civil signal

Table 2 *GLONASS civil signals*

Name	Center frequency [MHz]	Chip rate (Mcps)	Modulation scheme	Feature
L1	1598.0625 - 1609.3125	0.511	BPSK(0.5)	Single PRN code is transmitted by multiple frequencies because of FDMA modulation.
L2	1242.9375 - 1251.6875	0.511	BPSK(0.5)	Single PRN code is transmitted by multiple frequencies because of FDMA modulation.

The coordinate system for GLONASS complies with the PZ-90 (Parametri Zemli 1990), an ECEF coordinate system (The point of origin is the earth's center of gravity) that utilizes the geodetic reference ellipsoid. The time scale is synchronized within 1 ms of UTC (SU). However, since it makes allowances for leap seconds, as of September 2010, there is a 15-second difference to the GPS time that does not make allowances for leap seconds[2].

1.3 Compass/BeiDou-2

The Chinese global navigation satellite system, Compass/BeiDou-2, is a system that is being rapidly constructed in recent years. This is currently a regional navigation satellite system based in China with 5 satellites scheduled to be launched into the GSO (GeoStationary Orbit) and 27 satellites scheduled to be launched into the MEO (Medium Earth Orbit) including the quasi-zenith orbit. However, this system will provide a global service from 2020. As of summer 2010 (current), there are 3 satellites (1 satellite is a spare) operating in the GSO and one satellite operating in the quasi-zenith orbit (an inclined angle of 55 degrees), the world's first (August 1, 2010), and more satellites are scheduled to be launched in the future. Although the details of the signals are scheduled to be officially disclosed by ICD (scheduled around 2012), some details are being announced at international conferences, etc. The modulation format for the signals of all satellites already in operation is QPSK (Quadri-Phase Shift Keying). However, several BOC modulations (BOC: Binary Offset Carrier, ALTBOC: AlternativeBOC, MBOC: Multiplexed BOC) other than QPSK will apparently be utilized in the future. The civil signals scheduled to be transmitted in the future are shown in Table 3[3].

As the coordinate system, CGCS 2000 (China Geodetic Coordinate System 2000) is used, and the variance with ITRF is supposed to be several centimeters. The on-board atomic clock utilized a Swiss made Rb clock and Chinese made Rb clock. The time scale, referred to as BDT (Compass/BeiDou-time), is synchronized within 100 ns of UTC (The epoch time of BDT is 00d 2006). The time difference with GPST/GST (Galileo System Time) is said to be scheduled to be delivered.

1.4 GALILEO

In the EU, so that a global navigation satellite system that does not rely upon GPS could commence around 2010, the GALILEO programme commenced from 2002. Although the schedule was delayed as a result of the large costs involved and a conflict of interests between different countries, the experimental satellite, GIOVE-A, was launched in 2005 and was followed by the second one, GIOVE-B, which was installed with a passive hydrogen master and launched in 2008. By April 2011, 4 new satellites will be launched for IOV (in-orbit validation) and by the end of 2013, an addition 12 satellites (totaling 16 satellites) will be in initial operation. When the system is completed around 2017, there will be a total of 30 satellites (as of October 2010). An outline of the civil signals for Galileo is shown in Table 4[4]. Galileo also has adopted several BOC modulations (CBOC: Composite BOC, etc.).

As the coordinate system, GRTF (Galileo Terrestrial Reference Frame) that uses the earth's gravity as a point of reference is used,

Table 3 *Compass/BeiDou-2 civil signals to be transmitted*

Name	Center frequency [MHz]	Chip rate (Mcps)	Modulation scheme	Feature
B1-C	1575.42	1.023	MBOC(6,1,1/11)	L1-C/A compatible
B1		2.046	BOC(14,2)	
B2a	1191.795	10.23	AltBOC(15,10)	
B2b				
B3	1268.52	10.23	QPSK(10)	
B3-A		2.5575	BOC(15,2,5)	

Table 4 *Galileo civil signals*

Name	Center frequency [MHz]	Chip rate (Mcps)	Modulation scheme	Feature
E1	1575.420	1.023	CBOC (6,1,1/11)	L1-C/A compatible
E6	1278.750	5.115	BPSK(5)	
E5	1191.795		AltBOC(15,10)	
E5a	1176.450	I 10.230	BPSK(10)	L5 supported
		Q 10.230		
E5b	1207.140	I 10.230	BPSK(10)	
		Q 10.230		

and the differences with ITRF is supposed to be several cm. The time complies with TAI and although it has been announced that leap seconds will not be adopted, it currently uses the same leap second offset (19 seconds) as GPS[4]. Referred to as GST (Galileo System Time), this time scale is generated as an ensemble with a number of UTC times in Europe.

1.5 IRNSS

Although GAGAN (GPS Aided Geo Augmented Navigation), a SBAS (Satellite Based Augmentation System) for navigation utilizing GPS, is used in India, from around 2006, the IRNSS (Indian Regional Navigation System) is being promoted in the aim of developing an independent satellite positioning system which does not rely on GPS[5]. IRNSS consists of 7 satellites, 3 geostationary satellites and 4 quasi-zenith orbit satellites, in a quasi-zenith orbit with an inclined angle of 29 degrees to the equatorial plane. In addition to the Indian sub-continent, IRNSS covers a geographical area exceeding 1500 kilometers, provides a two frequency S band (2492.08 MHz) and L5 band (1176.45 MHz) and aims to have an accuracy within 10 meters. It seems that the S band is utilized due to the magnetic equator running through the Indian sub-continent and ionospheric variations having a strong impact. Ionospheric delay correction information is planned to be provided for single frequency users. However, although two types of modulation format, BPSK and BOC (5,2), are planned to be used for the modulation format, it is not shown in the Table since it is still in the planning stage and may be changed. The first satellite is planned to be launched in 2011 and scheduled for completion in 2014. The C band is also planned to be utilized for ranging.

As the coordinate system, WGS84 is utilized in conformity with GPS, and the IRNWT (IRNSS Network Time), time scale which is independently generated through the IRNSS Network Timing Center, is said to be planned for the time[6].

1.6 QZSS

Finally we will discuss the characteristics and issues relating to the QZSS, the first quasi-zenith satellite (QZS-1) launched on September 11, 2010 without trouble. The QZSS, the first satellite navigation system in Japan, consists of 3 quasi-zenith orbit satellites and transmits navigational signals that are highly compatible with GPS. The QZSS have been developed in the aim of “complements” and “auguments” the GPS. “Complements” refers to the increase of satellites that can be seen by users (Fig. 1) and “auguments” refers to technology that broadcasts special positioning signals which provide highly accurate positioning that cannot be acquired with GPS positioning alone. As a verification experiment using QZSS, the Geospatial Information Authority of Japan and the Electronic Navigation Research Institute plan to calculate the correction amount of the ionosphere delay error, the largest error in GPS positioning, from differences with reference stations of the GEONETs (GPS Earth Observation Network System), the world leading GPS observation system. They will broadcast the ionospheric delay information from the QZS-1[7]. The details are discussed below.

1.6.1 Signals

The signal modulation format is BPSK, the same format as GPS. In particular, some types of experiments are planned to be conducted under the theme of developing a system that reinforces the correction method of the variations of positioning signals. An independent signal referred to as LEX will be used for such experiments. An outline of the civil signals for QZSS is shown in Table 5.

1.6.2 Time Transfer Subsystem

The QSZ-1 is equipped with a highly precise Time Transfer Subsystem (TTS) (Fig. 2) developed by NICT. The TTS compares QZST (QZS time) synchronized with Japan Standard Time UTC (NICT) and the variation with GPST will be broadcasted as a UTC parameter. An outline of the technology is provided in the references of this paper[8]; satellite time transfer is the key technology for satellite positioning and by utilizing TTS, time differences can be compared with a higher accuracy than GPS. Furthermore, a function to especially receive and transmit the Ku band frequency for time transfer will be added.

1.6.3 Orbit

The QZSS is a satellite with an orbital inclination of 45 degrees in a geostationary orbit and is designed to move in a figure-8 orbit, and one of these satellites can be seen in the zenith vicinity above Japan for approximately 8 hours a day. However, since 3 satellites will be deployed in the same orbit with equal intervals, a satellite will become visible for 24 hours for the first time. Furthermore, each satellite will

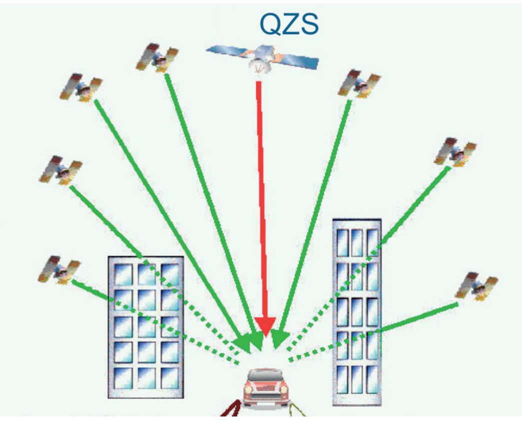

Fig.1 GPS complement by QZS

Fig.2 Time transfer subsystem (TTS) borne on "Michibiki"

Table 5 QZSS civil signals

Name	Center frequency [MHz]	Chip rate (Mcps)	Modulation scheme	Feature	GPS support
L1-C/A	1575.42	1.023	BPSK(1)	Most widely used civil signal	
L1C	1575.42	1.023	BOC(1,1)	Wider bandwidth than L1-C/A and robust for multipath	After 2014
L2C	1227.60	1.023	BPSK(1)	The second civil signal	supported from 2005
L5	1176.45	10.23	BPSK(10)	The third civil signal	supported from 2010
L1-SAIF	1575.42	1.023	BPSK(1)	Similar augmentation signal to SBAS	–
LEX	1278.75	5.115	BPSK(5)	QZSS original augmentation signal. The center frequency is same as that of Galileo E6.	–

be visible with a 4 minute lag each day and will circle once a year. In other words, not only will each satellite be visible for a short time, they will only be visible in the zenith during the night for a few months in one year. Consequently, 2 more satellites will be required for practical use.

In addition, JGS (Japan Satellite Navigation Geodetic System), a subset of ITRF (International Terrestrial Reference Frame) which is the most accurate coordinate system defined by the measurements of the earth based on space observations, is utilized as the coordinate system.

1.6.4 International compliance

In order to negotiate electric wave interferences with GPS, secure mutual operations and establish an overseas monitoring station, the GPS/QZSS technology working group for the QZSS has been actively conducted from 2002 through the Japan-U.S. GPS Plenary Meeting framework. In addition, in order to adjust the relationship between GPST and QZSST, the GQTO (GPS QZSS Time Offset) ICD (Interface Control Document)[9] was compared between NICT and USNO for the time control system.

The ICG (International Committee on GNSS)[10] was established to provide a place to make various GNSS adjustments. In regard to time scale control, the "Task Force Regarding Time" established within the WG-D "National, Regional and International Institutional Cooperation" has been attended since 2009.

1.7 Summary

A comparison of the spectrum composition for each GNSS discussed above is shown in Fig. 3[11]. Furthermore, although the coordinate system and time scale for GNSS do not completely match, it is agreed that each coordinate system complies with ITRF and there is only a discrepancy of a few cm. In regard to time scale, since the UTC that synchronizes each GNSS is different, it becomes necessary to mutually compare time in real time. However, GNSSs after GPS is mainly measured by calculating the time offset with GPS and then broadcasted. The coordinate systems and time scales utilized by each GNSS is shown in Table 6 below.

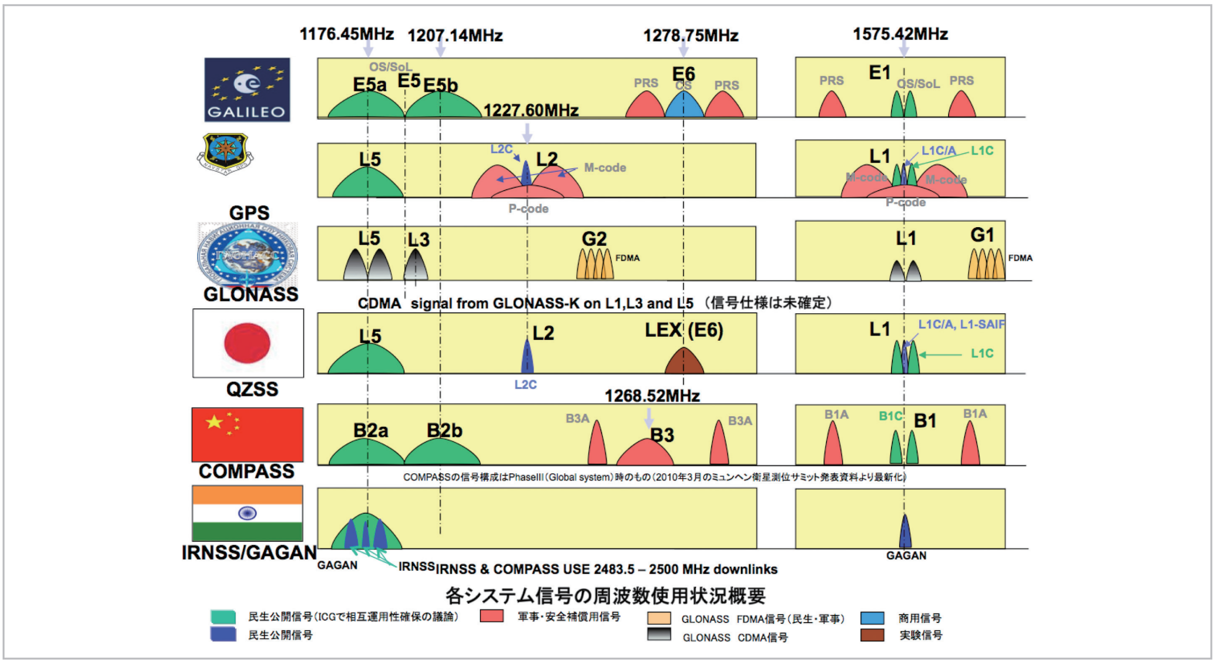

Fig.3 Comparison chart of spectrums among GNSSs and RNSSs [11]

2 Multi-GNSS

In the case that satellites are steadily launched as planed as discussed in the above **1**, it is said that the number of visible satellites around the world will become the number shown in Fig. 4 by 2020. Furthermore, the number of visible satellites particularly in the Asian longitude area will increase as result of the concentration of the GLONASS, the Compass/BeiDuo-2 and the Japanese QZSS. Since many navigation satellites will be visible earlier than other areas in the world, these are expected to be utilized as one enormous infrastructure. This simultaneous utilization of multiple GNSS is recently become known as Multi-GNSS. However, in order to actually utilize a number of GNSS with different frequencies, modulation formats and orbits, etc., as Multi-GNSS, international cooperation in the areas of standardizing data formats and publicly disclosing technical information is vital. Consequently, the MGA (Multi-GNSS Asia)[12], centered on Japan and Australia, was established in 2009 in the aim of promoting an experiment campaign as a "show case" through test experiments in order to determine how the new conceptual infrastructure will be utilized in the Asian longitude area that is experiencing an increase in the number of visible navigation satellites earlier than other areas.

Table 6 *Reference frames and time coordinate of each GNSSs*

	Reference frame	Time coordinate (sync)
GPS	WGS84	GPST (UTC(USNO))
GLONASS	PZ-90	GLONASS time (UTC(SU))
COMPASS	CGCS2000	BDT (UTC(NTSC))
Galileo	GTRF	GST (UTC(GST))
IRNSS	WGS84	IRNWT
QZSS	JGS	QZST (UTC(NICT))

2.1 Operations committee of the MGA and related institutions

Headed by Professor Akio Yasuda of Tokyo University of Marine Science and Technology and Professor Chris Rizos of the University of New South Wales, GNSS-related institutions and IGS, etc., in each region have participated as related institutions as well as JAXA of Japan, etc., as the center. The main institutions are listed below.

- Asia-Pacific Regional Space Agency Forum (APRSAF)
  http://www.aprsaf.org
- Civil GPS Service Interface Committee (CGSIC)
  http://www.navcen.uscg.gov/cgsic/
- European Space Agency (ESA)
  http://www.esa.int/esaNA
- Geo-Informatics and Space Technology Development Agency (GISTDA)
  http://theos.gistda.or.th/home_e.html
- Russia GLObal NAvigation Satellite Sys-

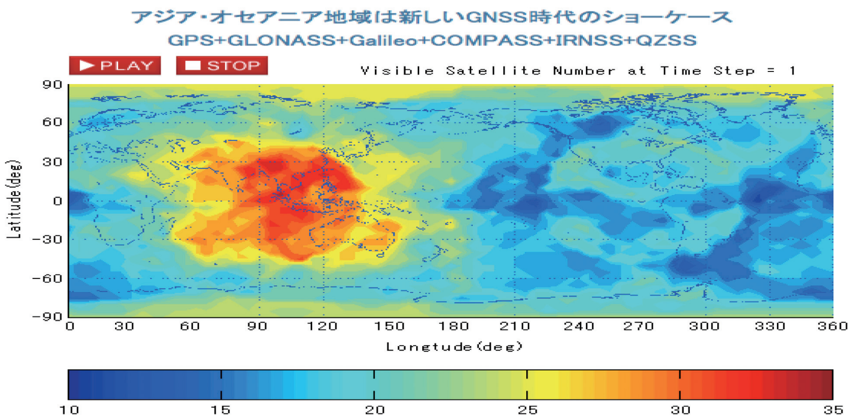

Fig.4 *Prospective numbers of visible satellites in 2020 (over 70 degrees in elevation angle)* [12]

tem (GLONASS)
http://www.glonass-ianc.rsa.ru/pls/htmldb/f?p=202:1
- International Committee on GNSS (ICG)
http://www.oosa.unvienna.org/oosa/en/SAP/gnss/icg.html
- International GNSS Service (IGS)
http://igscb.jpl.nasa.gov
- JAXA Quasi-Zenith Satellite System (QZSS)
http://www.jaxa.jp/projects/sat/qzss/index_e.html
- Satellite Positioning Research and Application Center (SPAC)
http://www.eiseisokui.or.jp/en/

2.2 MGA range of activities

The MGA is scheduled to conduct the following 3 central activities.

1. Formulate a technology base as infrastructure
2. Utilize, develop and verify the system
3. Promote active collaboration for these results and exchange information, etc.

Examples for each are summarized below.

Building Infrastructure: generating clock offset, time offset bias, ionospheric and tropospheric delay information, etc.
Utilization Development and Verification: disaster management, intelligent transportation systems, precise positioning, location based services and other mutual operations
Workshop Organizing: A workshop organization for deliberating joint projects and announcing results, etc., annually.

In regard to workshops, the First Asia Oceania Work Shop was held in Bangkok, Thailand in January 2010 in the aim of bringing together the opinions of the participating institutions. The second conference is scheduled to be held in Melbourne, Australia in November, in order to interact and exchange information for the construction of a specific observation network. The MGA plans to conduct the above 3 activities in two stages.

2011-2012 <First Stage of the Demonstration Experiment>

This is an experiment utilizing the GPS and QZSS prior to Multi-GNSS satellites being sufficiently capable of being utilized. This utilizes the existing GPS regional network in order to generate ionosphere and troposphere delay correction information and transmits variation correction messages for the region.

2012-2014 <Second Stage of the Demonstration Experiment>

After Multi-GNSS satellites become sufficiently capable of utilization, a demonstration experiment will be expanded to GNSS other than QZSS.

The MGA plans to construct a network to monitor Multi-GNSS during to the period from 2010 until the Stage 1 experiment. For example, it is said MGA plans to develop a multi-signal receiver and distribute it to the participants in the campaign experiment.

3 Specific utilization examples of GNSS and Multi-GNSS

In this Chapter, we will discuss a number of specific applications utilizing Multi-GNSS as a concept or previously conducted experiments. In addition, in the last section of this Chapter, we will introduce the experiments for Multi-GNSS proposed by the Space-Time Standards Group, NICT.

3.1 Car navigation and pedestrian support

Car navigation is the most representative GPS application and as the number of visible satellites increases, the positioning accuracy, visibility and reliability is expected to improve. If the accuracy become approximately 3 meters, car navigation will be capable of distinguishing roads. However, an accuracy of less than 1 meter is required for the navigation of small roads such as sidewalks. Although it is necessary to eliminate the impact of all types of variations as much as possible in order to achieve this less than 1 meter accuracy, it is technically difficult to eliminate the large ionosphere impact due to daily fluctuations on general-purpose single frequency receivers. In regard to the QZS-1, transmission experiments for ionosphere correction information utilizing reference points developed by the Electronic Navigation Research Institute and the Geospatial Information Authority of Japan[13] is being planned and highly accurate positioning is expected to be capable of general use (Fig. 5)[14]. If pedestrian navigation for sidewalks becomes stable, various services such as assistance for the disabled and elderly are conceivable. The expansion of geographic information services to consumers utilizing satellite positioning is also expected to achieve economic results as a part of the “G-Space Project”[15] proposed by the Ministry of Economy, Trade and Industry.

3.2 Precision agriculture

If accurate positioning becomes possible, machinery, etc., can be automatically operated from remote distances. Especially in area of agriculture, satellite images are expected to be used for monitoring land and creating work plans when different processes are to be conducted over a large area for each region. In addition, the nature of land will be able to be analyzed from color images, processes appropriate for the relevant land can be determined and crops will be able to be harvested remotely utilizing positional information (Fig. 6)[16].

3.3 Civil engineering and construction

Also in the area of civil engineering and construction, large-scale construction companies such as Komatsu Kensetsu are already using satellite positioning to create work plans, perform remote operations and conduct automatic excavations, etc. This use of satellite positioning information for large-scale construction is known as “information construction” and is one of the major technologies in Japan. However, satellite visibility for property development and construction in mountainous regions and between buildings is insufficient and remains the problem that the number of visible satellites is decreased. In particular, there are many cases when satellite positioning is unavailable during the daytime in summer and work had to be cancelled[17]. Since the zenith vicinity will be constantly covered by at least one satellite through the launching of QZSS in Japan and the number of visible satellites is expected to increase, it is anticipated that that this will function as a stable infrastructure in the future.

3.4 Disaster monitoring

It is extremely difficult to ascertain the location and scale of disasters in real time, especially in countries with large land masses such as China. The use of satellite positioning for preventing disasters in China remains an urgent issue. Consequently, China is dedicated to creating the independent global navi-

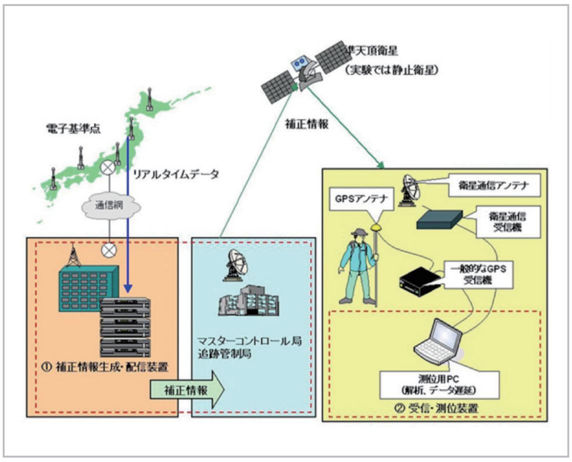

Fig.5 *Delay correction system by reference stations* [14]

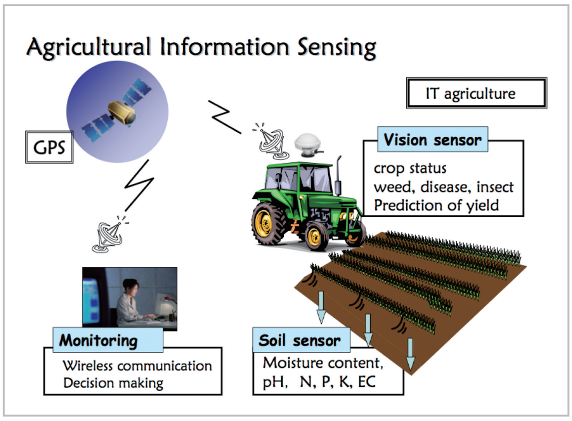

Fig.6 *An image of the auto cultivation system using satellite positioning* [15]

gation satellite system Compass/BeiDou-2. A characteristic of Compass/BeiDou-2 is that 3 geostationary satellites will be equipped with a communications function and as a result, the number of constantly visible satellites will increase. Furthermore, this will become a strong system with communication functions essential at times of disasters. This is a massed produced unmanned positioning system which can be used for rails over long distances with few stations and construction of large dams, and monitoring of accidents and disasters[18].

Although it is unfortunate that the QZS-1 is not equipped with the communications function in Japan, a country with many mountainous areas and unclearly visible land, geostationary satellites could be considered to form a part of the positioning system since a number of such satellites are equipped with communication functions.

3.5 Multi-GNSS experiment proposals

Here we will discuss the proposals of various experiments within the framework of the Multi-GNSS framework utilizing QZSS for the First Asia Oceania Work Shop, in which the Space-Time Standards Group, NICT also participated[19].

3.5.1 Time transfer experiments utilizing portable stations

Although NICT plans to conduct highly accurate time transfer experiments utilizing QZSS equipped with the Time Transfer Subsystem (TTS), there are only two fixed stations, one in Koganei and the other in Okinawa. Consequently, they plan to develop a portable station for ground time transfer system in order to conduct such experiments at any location. Since these portable stations can be transported using a trailer, time transfer experiments can basically be conducted at any location where QZSS are visible (Fig.7). However, it is necessary to find a location where atomic clocks can run steadily. Factors such as differences in ionosphere conditions between the two stations and the impact of the troposphere when elevation angle is low are a cause of large variations in time comparisons conducted on a long baseline, various physical effects such as relativistic effects caused by gravitational differences may be observed when conducting highly precise time transfer between long distances[20].

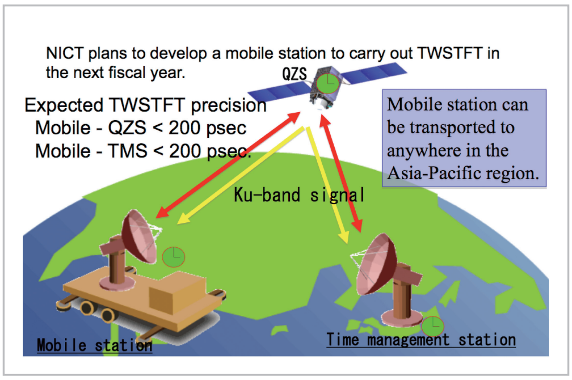

Fig.7 *Time transfer experiment between long baselines using the transportable earth station* [19]

3.5.2 Time dissemination experiments utilizing LEX signals

NICT will conduct experiments utilizing LEX signals, a L band experimental signal. Experiment periods and special message IDs will be allocated to different research institutions such as JAXA and the Geospatial Information Authority of Japan. NICT will formulate independent format and develop an exclusive LEX receiver using the ID No.21. A characteristic of LEX signals is the high broadband chip rate. Since information can be freely posted on navigational messages during experiments, NICT plans to use this for its time dissemination experiments. However, since LEX signals are L band, there is a large impact by the ionosphere. Experiments utilizing LEX signals are planned to be conducted on the prerequisite that time will be provided to single frequency users and the TEC (total electron contents) model developed by NICT Space Environment Group is scheduled to be utilized for ionospheric delay corrections.

3.5.3 Development of GNSS software receivers

With the modernization of GPS and the beginning of the Multi-GNSS era, some countries are developing and broadcasting its own independent positioning signals. Although hardware receivers are mainly used for satellite positioning, the problem of complying with new frequencies remains an issue. Conversely, software receivers are being researched and developed at a great pace in recent years, enabling compliance with signals to be possible at a low cost. Calculation bottlenecks at the time of utilizing software receivers can mutually process large volumes of data. However, data can be processed at an extremely fast rate by utilizing the recently developed GPU for calculations. Consequently, by developing low cost software receivers which are equipped with GPU and compatible with multi-frequencies, it is considered that flexible GNSS positioning can be achieved and numerous locations can be observed. NICT has experience in the independent development of signal sampling technology such as the VLBI sampler and is quite familiar with the technology used to develop software receivers. Since hardware receivers that are compatible with multi frequencies are still expensive, it is expected that software receivers will be useful for the purposes such as multipoint observations of the ionosphere.

4 Conclusions

In this paper we discussed each of the characteristics and progress status of multiple GNSS which have been rapidly constructed in recent years, and Japan's first navigation satellite system.

In addition, we also discussed the concept of Multi-GNSS as one large-scale infrastructure, and the considered and actual purposes of use of Multi-GNSS. In particular, it is anticipated that Asia longitude area (including Japan) will lead the world in increasing the number of visible satellites and these technologies will be utilized much faster than other areas in the world. Furthermore, we also discussed the experiments planned by NICT as the institution which manages QZSS time control. Japan, with its own world-leading domestic GPS observation networks, is expected to be a leader in the utilization of GNSS and the development of technology.

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