7

Effectiveness of the Quasi-Zenith Satellite System in Ubiquitous Positioning

TERUHISA TSUJINO
General Unit

1 Introduction

Recently, a variety of research is underway targeted at "ubiquitous positioning" in many countries including U.S.A., U.K., France and Australia. In Japan, for instance, a study on the application of ubiquitous positioning to the distribution of goods has been carried out by University of Tokyo. "Ubiquitous" means "existing at any place, at any time" or "omnipresent." In a future information society, methods for measuring precisely where you are will be as important and matter-of-course as ubiquitous hardware devices such as wearable computers and IC tags. This trend is heralded by the fact that millions of mobile phone users have signed up for positional information services. Although the positional accuracy currently available from mobile phone services is still low, even sometimes giving wrong information, the mainstream will shift to utilization of the Global Positioning System (GPS) for much higher accuracy. You can calculate your exact position using time signals from more than four GPS satellites simultaneously. GPS has already established itself as one of the key components of nation-level infrastructure and has been used in a variety of social activities.

In ordinary life, time is expressed in terms of hours, minutes and seconds. In ubiquitous positioning, your location is expressed in terms of degrees, minutes and seconds to the precision of one tenth second in both longitude and latitude[*1]. Linking positional information with other sources of information will also be a commonplace application; geographical information systems will show you the local area map, and other systems will provide interesting related information.

The Ministry of Internal Affairs and Communications (MIAC) has launched a research project, scheduled to be completed by April of 2007, to build a high-performance infrastructure, providing police, fire fighting agencies and maritime safety agencies with enhanced emergency calls capabilities for improved safety and freedom from care. Swift localization of the transmitter has been a longstanding challenge in mobile phone emergency calls. Mobile terminals with automatic positional information transmission capability using GPS will enable police to reach the spot much more quickly.

However, GPS positioning is often unavailable in areas without a clear skyline, such as mountainous terrain and densely populated areas, because sufficient GPS satellites are not in sight. This has been often pointed out as major blind side in GPS utilization.

The Quasi-Zenith Satellite System (QZSS), which will be complementary and augmentative with GPS, will be the most effective in solving this problem. System development will be carried out through cooperative effort between the public sector and governmental organizations, including the MIAC, the Ministry of Education, Culture, Sports, Science and Technology (MEXT), the Ministry of Economy, Trade and Industry (METI) and the Ministry of Land, Infrastructure and Transportation (MLIT), Japan's original satellites system will also provide substantial impetus and business opportunities to the aerospace industry.

This articles gives an overall picture of many aspects paving the way to ubiquitous positioning, including the status of the U.S. GPS satellite system and its inherent blind side, an overview of the emergency calls enhancement project initiated by the MIAC, the architecture and role of the Quasi-Zenith Satellite System, and research trends in enhanced positioning technology undertaken by ministries and research organizations. Quasi-Zenith Satellites can be multipurpose entities: they can be used, depending on the instruments they carry, for communications, broadcasting and monitoring as well as their original purpose of positioning. However, it is apparent that priority lies in positioning (complementation and augmentation of the existing GPS system) over other missions such as communications and broadcasting. I therefore propose that the role of the first QZSS system concentrate on complementing and augmenting the GPS system. I also propose establishing a governmental organization that presides over the entire project for the early implementation of a ubiquitous positioning system using the Quasi-Zenith Satellites.

2 GPS satellites system

2-1 Trends in GPS satellite development

The term GPS satellite (or navigation satellite) generally refers to the 24 NAVSTAR satellites operated by the U.S. Air Force (currently, five backup satellites have been added to a total of 29). As shown in Figure 1, the basic design of the system allocates 4 satellites in each of the 6 orbital planes. In addition, several backup satellites orbit the earth in preparation for malfunction or failure. Each satellite circles the earth in approx. 12 hours at an altitude of 20,200 km, roughly at midpoint between LEO (low-earth-orbit) and geosynchronous orbit. With its orbital inclination angle of 55° and high altitude, the system is able to cover almost all the earth's surface except a part of the polar regions. The Department of Defense (DoD) started investigation into satellite-aided positioning systems in the 1960s. After several stages of cut and try technical development, DoD launched the first NAVSTAR satellite in 1978.

As shown in Table 1, the NAVSTAR constellation started steady operation in 1990 (Block 2 and 2A) after completion of the validation phase (Block 1). Due to the life of these satellites, they are in a process that started in 1997 of being replaced by new satellites (Block 2R), and Block 2RM (the additional M stands for "Modernized") satellites with enhanced performance and an additional time signal for private sector use are scheduled to be launched shortly. Block 2F satellites with a newly added third time signal for private sector use are being constructed; the first one in this series is scheduled for launch in 2006. Furthermore, conceptual development for next-next generation satellites, or Block 3, is currently independently underway by

Figure 1 : NAVSTAR satellites and six orbital planes [1]

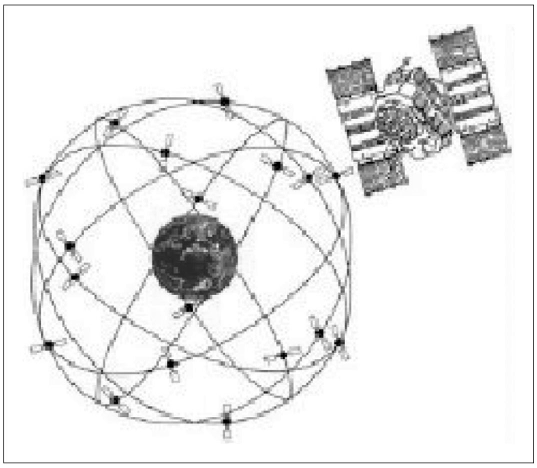


Table 1 : Global Positioning satellites launched by U.S.A.

Block	Manufacturer	Launched	Number	Orbital inclination	Weight (kg)	Design life	Power
1	Rockwell International	1978-1985	11	63°	759	5 years	0.41kW
2		1989-1990	9	55°	1,660	7.5 years	0.71kW
2A		1990-1997	19	55°	1,816	7.5 years	0.71kW
2R	Lockheed Martin	1997-2006	2R 12 2RM 7	55°	2,032	10 years	1.14kW
2F	Boeing	2006-2012	33	55°	2,160	15 years	2.44kW
3	Lockheed Martin/Boeing	Undecided (201?-)	Undecided	Undecided	Undecided	Undecided	Undecided

Lockheed-Martin and Boeing. DoD will soon decide the main contractor for development and manufacturing Block 3 satellites between these two manufacturers.

2-2 Functional aspects of GPS satellites

The current workhorses of the NAVSTAR constellation, Block 2A and 2R, carry two types of atomic clocks and constantly broadcast the precise time base signals according to their own clock and orbital elements once every second. They are capable of sending time base signals practically to a precision of 10^{-9} to ground GPS receivers.

A technical specification common to all blocks is the frequency of the transmitted signal. Current GPS satellites use two frequencies: L1 centered at 1575.42 MHz and L2 at 1227.6 MHz. These frequencies should not be changed even in the future, as this is prerequisite for the continuous use of ground receivers. Note, however, a plan to add a new frequency (L5: centered at 1176 MHz) that will be open for private sector use (proposed for use as a civilian safety-of-life signal) is underway for implementation in Block 2F satellites. This proposal has been approved by the International Telecommunication Union - Radio Communication Sector (ITU-R).

2-3 Non-U.S. positioning satellites

Russia has deployed the Global Navigation Satellite System (GLONASS) using its proprietary positioning satellites. Due to the dwindling number of normally operating satellites, Russia plans to launch about 10 replenishment satellites starting in 2005. Although it has limited usefulness due to the sparsely populated constellation, the signal from GLONASS is available in Japan. Instruments capable of receiving both GPS and GLONASS signals are also on the market.

European countries currently depend on GPS satellites of U.S.A. for their positioning needs. However, the European Union (EU) and the European Space Agency (ESA) are now jointly pursuing the Galileo project aimed at possessing their own Global Navigation Satellite System (GNSS). The Galileo positioning system promises global utility, and non-European countries such as China, India, Israel and Brazil have decided to become partners in the project. It is planned that a constellation of 30 positioning satellites, GNSS, be launched within a few years. When the project enters the deployment phase, 8 satellites will be launched at a time using an Ariane V launch vehicle.

China has launched three “Beidou” geostationary positioning satellites of its own, and they are mainly used for traffic control and car-theft monitoring. India is also planning to launch a GPS augmentation satellite, “Gagan (sky).” The geostationary satellite is positioned at a high angle of elevation near the zenith over India's southern high-tech industrial area including Bangalore. These regions will enjoy full geographical advantage for ubiquitous positioning by having a GPS complementation satellite just above them.

2-4 GPS complementary and GPS augmentative

In locations without major obstructions, the position of the receiver can be easily and accurately determined using GPS signals. This is essentially the case with the U.S. forces: the main areas in which they use the NAVSTAR are in open sky and sea, enabling them to exploit the full potential of the system. In civil use, however, there is a possibility of the signal path being obstructed by the jungle of high-rise buildings in densely populated area or canyons in mountainous terrain, meaning the required number of signals for accurate localization cannot be received. “Availability” is the term used to represent the probability that you can use GPS services properly in a particular place. Many urban areas in Japan have availability somewhere between 30 to 40%. A survey conducted in the West Shinjuku area (Shibasaki Laboratory, University of Tokyo)[2] revealed that a large proportion of residential areas with narrow roads and dense residential areas have limited availability in addition to downtown with its high-rise buildings.

Positioning errors are also an important factor to be considered. In civilian applications of GPS positioning, errors greater than 10 meters may arise due to such factors including: propagation delay in the ionosphere, time base signal error, positional information error of the satellite, delay due to water vapor in the troposphere, and multipath signals on the ground. The main source of error is delay in the ionosphere. However, this error can be compensated for using the frequency difference between L1 and L2. Error compensation using two frequencies will be available for civilian applications when Block 2RM of GPS satellites is launched.

Low availability and measurement errors have been pointed out as drawbacks in the use of GPS, and the U.S. itself has admitted the need for systems to complement and augment GPS satellites.

"Complementary" and "augmentative" systems have distinct meanings that must be clearly defined.

"GPS complementary" is to allocate a satellite (corresponding to one GPS satellite) at the near-zenith position at all times. A near-zenith satellite transmitting the L-band time based signal and positional information can be actually implemented.

"GPS augmentative" would be to improve GPS accuracy, where, for example, a network of fixed ground-based reference stations analyzes errors in the signals received from GPS satellites and produces corrective information as well as integrity information for improved accuracy; this information is distributed to other receiver stations via various communication links. This method is called Differential GPS (DGPS).

Methods for distributing GPS augmentative information to end users have already been implemented on a chargeable basis using ground-base FM broadcasting, or by mobile phones. However, these services remain inaccessible to some regions. If we have a near-zenith satellite in place, even regions that cannot be reached from ground-base stations can access GPS augmentative information by relaying the S-band signal. GPS augmentative information may differ from one locality to another; it is a subject of future discussion as to how many meshes are required to cover the whole of Japan for consistent augmentative information processing.

3 DOP number that determines GPS accuracy and minimizing atomic clock

3-1 DOP number

To accurately determine 3-dimensional coordinates, you have to receive signals from four or more of the satellites. It is desirable that the four satellites be spatially arranged so that the Dilution of Precision (DOP) number is as near to 1 as possible.

DOP is the index number that describes the geometric quality of a GPS satellite configuration in the sky. Ideally, one satellite at the zenith and other three satellites, shifted 120° from each other, constitutes a regular triangular pyramid. This ideal configuration is represented by a DOP number of 1, and it increases as the shape of the pyramid deviates from the ideal configuration. The number is calculated by comparing the actual volume of the triangular pyramid with that of the ideal configuration. GPS receivers with accuracy-setting capability can use a DOP number for setting their own accuracy level. Although a DOP number of 1 is desirable, it is very rare that a GPS satellite is actually close enough to the zenith at any one time. In this respect, a Quasi-Zenith Satellite in place can be an effective complementary method to the GPS system, so that the DOP number can attain value near 1.

3-2 Minimizing atomic clock

The GPS satellite is an ultra-high precision atomic clock orbiting the earth. Block 2 and subsequent NAVSTAR satellites carry two types of atomic clock: the cesium clock and the rubidium clock.

Atomic clock components used to be very large. Recently, however, with the development of portable atomic clocks[3], they have become small enough to fit in individual aircraft and vehicles of U.S. forces. These machines had to receive time base signals from positioning satellites to obtain exact time information, but satellite signals have often had to be replaced by the portable atomic clock.

The U.S. Defense Advanced Research Project

Agency (DARPA) has been undertaking research into fabricating ultra-small atomic clock chips of less than 1 cm^3. If grain-sized atomic clock chips become a reality, they will surely be integrated into ordinary hand-held devices. Such a device could be used for positioning applications on a par with GPS satellites, making exact positioning possible even if the signal from one of the GPS satellites is obstructed.

4 Trends in GPS satellite application in Japan

4-1 Framework for GPS satellite application

Japan, as well as other countries, shares in the bounty of GPS, which is owned and operated by the U.S. It has already become an essential component of our social infrastructure, and many of our activities could not take place without it. Can we completely rely on the infrastructure provided by another country?

In a Japan-U.S. joint communiqué issued in September 1988, U.S. President Clinton and Japanese Prime Minister Obuchi declared that U.S. would continue to provide GPS services free of charge to the whole world, and Japan would cooperate in enhancing GPS application technology. In October of the same year, the U.S. House Representative and Senate both passed a bill that prevented the President from changing this open GPS policy without the approval of congress. These developments have enabled Japan to use GPS information without anxiety, at least for the foreseeable future, and manufacturing and sales of car navigation systems in Japan took a sudden upward jump[4].

Although there is certain assurance for the continuous, unobstructed use of GSP, there is still some insecurity that access to the GPS system might one day terminate or precision will degrade in line with U.S. policy change. One solution would be for Japan to launch its own constellation of GPS satellites using proprietary Japanese technology.

4-2 Typical application of GPS

The main use of GPS lies in acquiring positional information with a variety of applications including car navigation, Geographical Information Systems (GIS), geographical markers, cadastral surveys, and crustal movement monitoring. There are many other applications: meteorological observation using the delay in electromagnetic waves, anemometric observation at sea using reflected electromagnetic waves, and reference clocks that solely use time base information. In exploiting Quasi-Zenith Satellite resources, the most advantageous application would be enhancing emergency calls, especially the automatic notification of a transmitter's location.

4-3 Enhanced emergency call

With the amazing prevalence of mobile phones in recent years, more than half of police notifications are transmitted using mobile phones.

When an emergency call is sent from a fixed-line phone, the sender can be easily located using the telephone directory database. For mobile phones, however, few good methods are available to pinpoint transmitter location with sufficient precision. In August 2003, IT Strategy Headquarters stated that localization and positional information notification of the transmitter used for emergency calls must be positioned among the most important and urgent agenda items in the e-Japan Priority Policy Program.

The U.S. government has made it mandatory, since 1999, that mobile phone carriers equip their devices with automatic positional information notification capability when the subscriber makes a emergency call (#911), which is called Enhanced 911 (E911). The EU has also decided to introduce E112 in 2002. Implementing this emergency mechanism, however, has not made much headway. In U.K. and Germany, legislation review is underway to make this mechanism mandatory.

In Japan, the decision made by the IT Strategy Headquarters is equivalent to introducing a Japanese version of E110 (police), E119 (fire fighting) and E118 (maritime safety).

Following the IT Strategy Headquarters' decision, the Minister for Internal Affairs and Communications, Mr. Taro Aso, submitted this subject to the Information and Communications

Policy Site (chaired by Mr. Yoshihisa Akiyama) for deliberation ("Enhancement of Emergency calls in Telecommunication Policy"). The committee returned some of the deliberation results as "Technical provisions required for subscriber localization in emergency calls" (June 30, 2004)[5].

The report (partial) is mainly based on discussion in the Enhancement of Emergency Calls Committee (a subdivision of the Information and Communications Policy Site: chaired by Prof. Norihisa Doi, Chuo University), whose constituent members are mainly mobile phone carriers such as NTT DoCoMo, KDDI, and Vodafone.

This partial report discussed the status of emergency calls from mobile phones and the need for positional information notification, technical conditions related to positional information notification, the time schedule, items to be implemented and future assignments.

The schedule for implementation is as follows. Handling of positional information in emergency calls will start in April 2007. After this, on-board positional information notification capability will be compulsory for all new and updated mobile phones. The projected prevalence of mobile phones with this function will be 50% by 2009, and 90% by 2011.

4-4 Effect of enhanced emergency calls

With the rapid increase in emergency calls from mobile phones, the quick localization of the transmitter is sometimes difficult. In fact, the average time required to reach the spot has become longer by 1.5 minutes (32%) in these ten years in Japanese major cities (ordinance-designated cities). The deterioration is especially visible in these two or three years. However, note that the overall time from the occurrence of accident/incident to notification to the police or related agency must be shorter because callers without mobile phones must have found a fixed-line telephone in the first place, which may have taken a considerable time. With the prevalence of mobile phones, it has become common that multiple emergency calls reach the authorities simultaneously, making the situation more confusing; there may be calls from multiple witnesses of a single incident or independent witnesses of multiple incidents. Enhancing the emergency call capability of mobile phones (for example, E110) is expected to reduce the total time and aid proper judgment for emergency action.

If a large-scale disaster occurs, communication using fixed-line phones may be severely restricted. However, emergency response mechanisms are already in place to give highest priority to emergency calls and maintain the flow of communication.

4-5 Accuracy of positional information communication

According to the partial report, the required accuracy of positional information is as follows: positional accuracy should be within a radius of 15 m (best-case scenario), and the information is represented by a latitude and longitude value (in 0.1 sec unit) and altitude (in 1-m units). The basic method of obtaining positional information is to use GPS signals from four or more GPS satellites; in this case, the practical accuracy of the data is somewhere between several meters to several tens of meters. When there is not a sufficient number of GPS signals available, for example, in densely populated urban areas or inside buildings, a synchronization signal from a base station will be used instead, in which case positional accuracy will deteriorate considerably from tens of meters to hundreds of meters. Even this synchronization signal may be unavailable in areas such as underground cities and indoors, where cell-based positioning will be used. In cell-based positioning, cell IDs that were obtained from mobile terminals are stored in a positioning server's database, and the relevant positional information is searched from this database. The positional accuracy of the cell-based method depends on the density of the base station network; typical values are several hundreds of meters in urban areas and about ten thousand meters in regional areas.

In an open-sky environment, positioning using GPS signals has clear advantages. However, this does not apply in the majority of urban areas, even in low-rise shopping areas and residential areas. Full-fledged enhancement in emergency calls, as we expect it to be, may not be realized if we completely depend on information provided by U.S. GPS satellites because of their low availability.

To mitigate these problems, the Japan Aerospace Exploration Agency (JAXA: an independent administrative entity) is planning to launch a geostationary Engineering Test Satellite VIII (ETS-8) equipped with time signal transmission capability around 2006. It will be used to validate high-precision positioning. Although, with its low elevation angle of 45°, it will have limited capability to complement GPS, the satellite is expected to play an important role in enhanced emergency calls (E110, E119, and E118) development.

5 Mechanism and roles of Quasi-Zenith Satellites

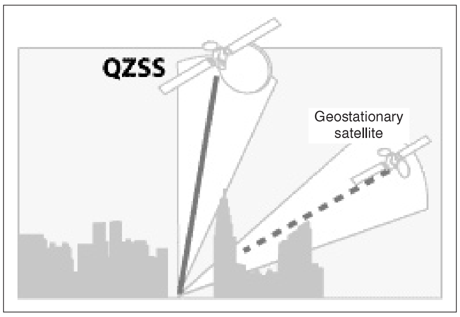
5-1 What is a Quasi-Zenith Satellite System?

The Quasi-Zenith Satellite System (QZSS) is a constellation of three satellites that orbit the earth in synchronously with the rotation of the earth (23 hours 56 minutes) on different orbital planes, with at least one satellite positioned near the zenith over the country at all times, in low to middle latitude on the same line of longitude. The geostationary satellite, on the other hand, is positioned over the equator at all times, orbiting every 23 hours and 56 minutes, and its position is controlled from ground stations so that is does not deviate from the fixed angle. Viewed from the middle latitude regions, the geostationary satellite is often invisible from the ground obstructed by buildings and mountains due to its low elevation angle (around 45 degrees at most). The three Quasi-Zenith Satellites round the earth reciprocating the northern and southern hemisphere with their orbits cutting a figure of 8 when projected onto the earth's surface. The trajectory takes various orbital inclination and eccentricity values, but is always centered on a certain longitude.

5-2 Practical example of QZSS and research history in Japan

In the United States, Sirius Satellite Radio launched three Sirius satellites for radio

Figure 2 : Comparison of Quasi-Zenith satellites and Geostationary satellites



Source: JAXA home page [6]

broadcasting covering the entire American continent. The number of subscribers has just recently exceeded 700,000, with a subscription fee below $10 a month. The company forecasts that the number will finally reach 50,000,000. The Sirius satellites (3.8 ton/satellite) were launched one by one using the Proton K launch vehicle provided by International Launch Services (ILS). The satellite bus for the Sirius system is the LS-1300 series provided by Space Systems/Loral, the same series as Japan's MTSAT-1 (Multi-functional Transport Satellite). Because of the vast stretches of the American continent, "near-zenith" conditions cannot be maintained at all places. It is therefore questionable to classify the Sirius constellation as a Quasi-Zenith Satellite system. Figure 3 shows the Sirius constellation orbits, which look similar to those of QZSS.

The idea of Quasi-Zenith Satellites is long standing in Japan. For example, the idea was put forward in 1972 by the Radio Research Laboratories (Ministry of Post and Telecommunications), which was the predecessor of the current NiCT (National Institute of Information and Communication Technology)[8]. Based on the technology level of that time, the plan to launch a constellation of satellites was abandoned; decision and control of the orbit was difficult, and the amount of fuel required for orbital modification was excessive. Later that decade (1997), as awareness of the importance of proprietary positioning satellites as a national infrastructure deepened, discussion resumed, and a national project for Quasi-Zenith Satellites was conducted. In 2002, Advanced Space Business Corporation (ASBC) was established to promote QZSS development. ASBC is a joint venture between private companies. From 2003, with the decision to allocate government budget to related ministries (MIAC, MEXT, METI, and MLIT), the full-fledged project has just begun.

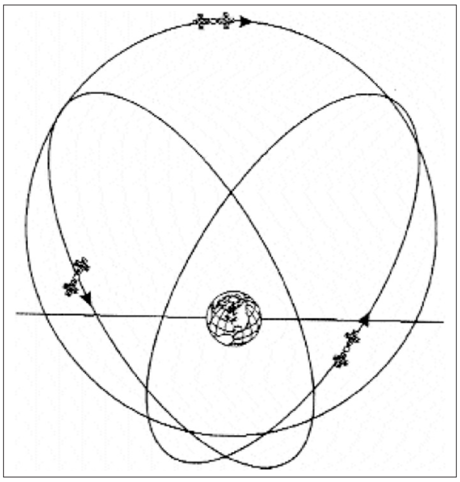
5-3 Basic structure and role of GPS complementation QZSS

(1) Functions of satellite

For GPS complementation, the Quasi-Zenith Satellite must carry atomic clocks and antenna for broadcasting as required mission instruments. It also includes satellite bus including body structure, solar panels, power equipments, altitude control system (including propulsion systems), TT&C systems, and thermal control systems. The satellite is launched by a launch vehicle into the geostationary transfer orbit, and then the final transition is made to a predetermined satellite orbit using an apogee engine. The satellite must be mounted with an apogee engine for this operation (note that, if the satellite is launched using a four-stage launch vehicle, such as Russia's Proton, an apogee engine is not required on the satellite side).

To transmit GPS augmentation information, the satellite must carry transponders to receive augmentation information from the ground station and broadcast to the ground. Figure 4 shows an external view of planned full-fledged version (with positioning, communication, and broadcast capability) of the Quasi-Zenith Satellite.

Figure 3 : Orbital planes of Sirius satellites

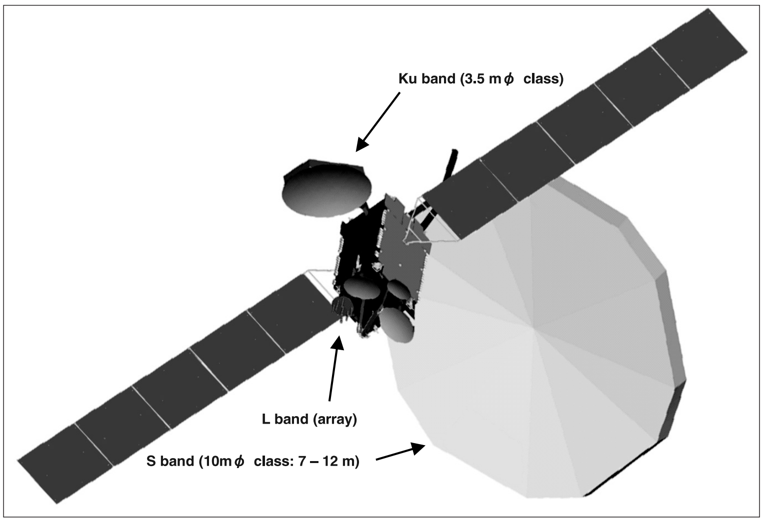


Source: ILS document[7]

(2) Orbit of Quasi-Zenith Satellite

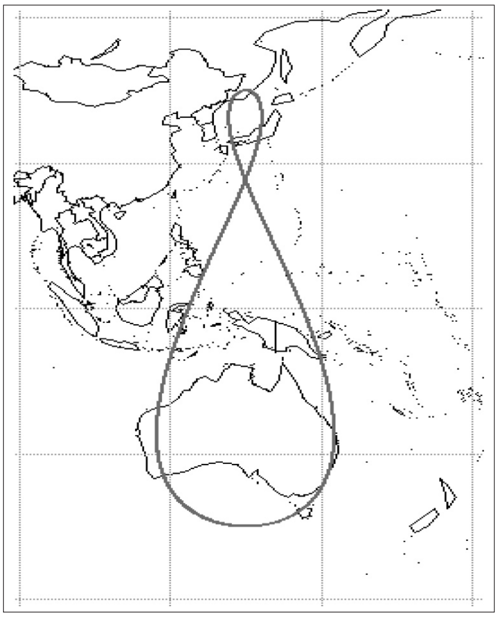
Figure 5 shows the planned trajectory of the Quasi-Zenith Satellite. To realize this trajectory, orbital elements are designed in the following way. First, semi-major axis is designed to be the same as that of the geostationary orbit. The apogee must be larger than this by 3,000 to 5,000 km, and the perigee must be smaller by the same amount. The resultant ellipsoid is relatively near to a regular circle, with one of the two focal points coinciding with the center of

Figure 4 : External view of Quasi-Zenith Satellite (plan)



Source: ASBC document

Figure 5 Example of Quasi-Zenith Satellite trajectory projected on the earth's surface



the earth and other focal point lying within the earth. The eccentricity for this ellipsoidal orbit is approximately 0.1.

The orbital inclination is about 45°, covering the sky in Japan to as far as Australia.

Placing three satellites those are shifted 120° RAAN (Right Ascension of Ascending Node) to each other makes three orbital planes, enabling a constellation arrangement so that the satellite in each orbital plane covers the Zenith over Japan in succession. The argument of perigee is an important parameter in determining the 8-shaped trajectory; setting this parameter to 270° enables the placement of the apogee in the northern hemisphere. Figure 6 shows an example of the zenith viewed from the bottom of an urban canyon. It is almost impossible in this location to receive a signal from a geostationary satellite as it is placed south at a small solid angle extending from east to west. The Quasi-Zenith Satellite remains overhead for approximately eight hours with an elevation angle of 70° or more. As it heads south, another satellite comes overhead from the south (hand-over) and remains in sight for 8 hours. Thus, three satellites enable round-the-clock coverage.

(3) Applications other than positioning

As an option, a Quasi-Zenith Satellite System design that includes broadcasting and communication capability is also under consideration. As the satellite moves at a near-zenith angle, it will enable communication and TV-broadcasting even in urban canyons and deep mountainous areas with a help of large antenna-carrying vehicles in place. At present, many communication/broadcast carriers prioritize the application of geostationary satellites and surface waves. They are not very eager to promote QZSS for these purposes. However, when QZSS is realized and starts providing positioning information services, it may trigger new applications in the communication and broadcasting area.

Figure 6 : Overhead view from the bottom of an urban canyon

Source: Courtesy of National Institute of Information and Communications Technology

(4) New business opportunities in aerospace industries

The successful application of the Quasi-Zenith Satellite System in Japan to implement ubiquitous positioning can trigger needs in other countries, which may result in business inquiries. Depending on the size of the 8-figured orbit, more than one QZSS constellation may be required in regions with wide stretches of land such as Europe and the American continent. The orbit of Quasi-Zenith Satellite is still an untapped resource with great promise compared with the geostationary orbit already in a state of depletion. The success of the QZSS project can bring new business opportunities to aerospace industries in Japan.

6 Research trends for enhanced positioning accuracy in Japan

6-1 High precision time control technology (MIAC)

The National Institute of Information and Communication Technology (NiCT: an independent administrative entity) is developing a hydrogen maser clock, a high-precision atomic clock that will be mounted on the Quasi-Zenith Satellite. In addition, research on the timing control system used in ground stations is underway, which will enable synchronization with the satellite to sub-nano-second precision ($< 10^{-8}$ sec)[9]. Using this hydrogen maser clock, it is expected that the Japanese QZSS will have the world's best timing accuracy.

To support these efforts, the Information and Communication Policy Bureau of MIAC is now drafting technical guidelines for S-band satellite communication, which will be required in GPS augmentation using Quasi-Zenith Satellites.

6-2 High-precision positioning experiment system (MEXT)

In the joint effort of four ministries, the Research and Development Bureau of MEXT presides over the entire progress of the experimental system for high-precision positioning. JAXA is undertaking research to estimate and forecast orbital information with very high precision, and broadcast it to users. Multiple monitor stations located in and outside Japan receive positioning signal broadcast by the Quasi-Zenith Satellite, and the orbit and time information of the Quasi-Zenith and GPS orbital elements are estimated and forecast based on these signals. The feasibility of satellite-borne experimental instruments is also under study aimed at higher performance and precision in the next-generation positioning system. These include a device for inter-satellite ranging and an ultra-high-precision accelerometer.

6-3 Key technology for a lighter satellite with longer operating life (METI)

METI's "Development of Fundamental Technologies for Next-Generation Satellites" project is undertaking a variety of elemental technology developments including: a high-efficiency thermal control system incorporated in satellite body structures, next-generation ion engine, a composite material for large body structures, and a satellite-borne lithium battery. The ion engine has a larger specific impulse and longer life than conventional chemical rockets, which make it a better thrust source for controlling the Quasi-Zenith Satellite orbit. Elemental technology development for the lithium battery has been assigned to New Energy and Industrial Technology Development Organization (NEDO: an independent administrative entity).

6-4 High-precision positioning system with GPS (MLIT)

Civil Aviation Bureau of MLIT is developing MTSAT Satellite-based Augmentation System (MSAS). This MTSAT (Multi-functional Transport Satellite)-aided system was planned for advanced air navigation, and it has almost reached the stage ready for operation. Reliability factors for this system such as integrity and service consistency, as well as accuracy and availability, have already been verified[10]. However, MTSAT must be put into practical operation before MSAS starts operation. The launch of the MTSAT-1R satellite is scheduled for February 2005 (this is a replacement satellite for the MTSAT-1 that was lost in 1999 due to the unsuccessful launch of the H-II launch vehicle).

The Electronic Navigation Research Institute (ENRI: an independent administrative entity) is undertaking, as well as MSAS-related studies, research into Quasi-Zenith Satellite-aided high-accuracy positioning systems. In 2003 and 2004, ENRI developed an analysis system that generates GPS augmentation information from the GPS signal received by electric reference points located throughout Japan. This was an off-line data processing system. From 2005, ENRI has started developing an on-line real-time system for processing data from electronic reference points and for generating GPS augmentation information. The development of receiver prototypes is also included in the project. ENRI is also studying an integrity monitoring method for Quasi-Zenith Satellites based on the results of the MSAS research.

6-5 Enhancement of positioning accuracy

Thanks to the concerted efforts of three Ministries (MIAC, MEXT, and MLIT) to refine high-precision positioning technology and application to the Quasi-Zenith Satellite System, the current level of lateral error by GPS positioning (approx. 11 m) will be reduced to less than 1 m. In addition, contribution to errors from such factors including the ionosphere, time accuracy, satellite position, and troposphere are reduced by magnitude of 1-digit to a level measured in centimeters. With these enhancements in positional accuracy, position display in 0.1 sec will serve its purpose.

7 QZSS will further expand GPS applications

The complementary effect provided by QZSS to GPS will not be limited to enhancing emergency call processing. Various GPS applications have been explained in 4-2. The following are some examples of how QZSS can complement and augment GPS in many fields of application.

(1) Navigation

Car navigation systems commonly used in Japan have on-board autonomous navigation or map-matching functions, as well as having GPS receivers. They navigate the driver by displaying the car's present position on the map using a combination of these technologies. The current level of accuracy is sufficient for ordinary car drivers. For the main navigation system for pedestrians, KDDI provides mobile phones with a GPS receiver function. However, automatic position notification to the police in the case of emergency has not been implemented. The E911 system in the U.S. is not necessarily highly valued because of the low availability of the required number of GPS signals. Areas where four or more GPS satellites are simultaneously in sight are scattered. By the same token, the enhanced emergency call system to be introduced in Japan in 2007 may not show its full potential. However, by complementing and augmenting GPS using QZSS, this problem will largely disappear. At the same time, I confidently expect that the hand-held navigation device and Location-Based Service (LBS) market will grow dramatically.

(2) Railway traffic control

When applying control using GPS to a railway network that includes mountainous areas, the unavailability of the required number of GPS signals will largely nullify the benefit of the control system, just as is the case with car navigation. This problem can be largely solved if a satellite is always positioned at a near-zenith angle. The National Traffic Safety and Environment Laboratory (an independent administrative entity) installed a pseudo Quasi-Zenith Satellite in Kumamoto city and carried out a control experiment using GPS[11]. The experiment was carried out in cooperation with the Kumamoto city transportation authority.

According to the report, the time ratio with signal availability increased from 24% to 72%, which clearly demonstrated the effect of the Quasi-Zenith Satellite. In addition, the feasibility of train position detection with 1-m precision was well demonstrated. It pointed out, however, that to control trains running at high speed, measures are required to eliminate the blurring effect caused by multipaths.

A similar experiment was carried out by Future University-Hakodate (Hakodate city).

(3) Land Survey

The use of GPS will promote efficiency in land survey. Conflict of interest often occurs in relation to demarcation of land, and differences of interest are often settled in court. The future trend in this field is that land demarcation will be determined by electronic means, based on the exact electronic survey results of public property (including roads and rivers). The "Electric Survey and Demarcation of Public Properties" project is in progress supported by more than hundred members of the Diet. According to the Japan Federation of Survey Planning Association, surveys using GPS are only useful in limited areas and at certain times, so the project presupposes the use of conventional transit surveys, eliminating the use of GPS. In this case, it is forecast that it will take nearly 200 years to complete the demarcation of all places in Japan (including privately owned land). The reason for the elimination of GPS is that the satellite is in sight for only a limited period of time, and the signal is easily obstructed by mountains and nearby buildings (generally, GPS survey is unavailable in places where the elevation angle is less than 15°). Introduction of the Quasi-Zenith Satellite that complements the GPS signal will enable more efficient GPS-aided surveys, and the whole process of land demarcation will very probably be completed in the first half of this century.

(4) Other applications

The Forum for Social Basis in Enhanced Positioning (a Non-Profit Organization) set up a committee (Round-Table Conference of Satellite Positioning Users: chaired by Prof. Ryosuke Shibasaki, University of Tokyo) and compiled a report "Proposals for Satellite Positioning System: Perspective from Private Sector"[12]. This report pointed out that, in addition to the applications mentioned in the previous sections, various sectors would greatly benefit from ubiquitous positioning including quick-to-spot businesses, sightseeing, management of goods or waste disposal, maritime construction, and robotics.

Only a few possible QZSS applications are given above. QZSS, as one of the key national infrastructures, will activate various sectors in industry, and promote the development of new products and services.

8 Conclusions — Proposals to promote QZSS development—

Ubiquitous positioning will change many aspects of our lives; it is expected to improve the level of security and safety, and to enhance economic activities. However, the U.S. GPS, an essential part of ubiquitous positioning, has a serious blind side, because it is a go-around satellite, it is obstructed depending on the location and time. This is the inherent nature of GPS that can hinder the full exploitation of its capacity as the most basic positioning method. Truly ubiquitous positioning requires a quasi-zenith satellite to be positioned above us at all times, and complements and augments GPS. It has often been pointed out that aerospace development projects in Japan have few elements that arouse the interest of the general public. The Quasi-Zenith Satellite is an exception in this respect, and can be a national infrastructure that will support our lives and industries for 50 or 100 years to come. The project is gathering huge interest from all quarters, and will be pushed forward by the Japanese government.

Although QZSS has great technical potential such as communication and broadcasting as well as positioning application, it seems that implementing all these aspects simultaneously will entail excessive difficulties in terms of technology and development framework. This approach may hinder the early completion of the system. Among these aspects, positioning application is of utmost importance and urgency as a key infrastructure of a nation, and can be a driving force of social renovation and the creation of new values. I propose that the first QZSS concentrate on functions that complement and augment GPS. This will enable steady, rapid development and the early implementation of ubiquitous positioning, which will greatly contribute to the enhanced safety and security of citizens, and to activating the economy by providing brand new services.

The Council for Science and Technology Policy (CSTP) decided in Sept. 2004 that the governmental organization by which all development efforts and operation framework of the QZSS "should be determined at the early stage before completion of QZSS feasibility studies." This was a step forward; before this, CSTP had proposed that government organization was to be decided "when QZSS feasibility studies were complete." However, Japan is still lagging behind U.S., which already has an organization called Interagency GPS Executive Board (IGEB) and its sub-committee, GPS Interagency Advisory Council (GIAC)[13], which decides development policy and distribute resources. Although each organization is making efforts to solve its own technical problems, we do not have the principal organization to lead the whole process of development and to be responsible for the collective agenda such as the economic feasibility and integrity of the satellite system.

To promote the well balanced development of the wide area relating ubiquitous positioning, and especially for the rapid realization of the QZSS, I strongly recommends the establishment of a governmental organization, like the IGEB in U.S.A, that will preside over the entire progress in related fields.

Acknowledgements

The subjects and discussion in this paper are inspired by the lecture delivered by Mr. Hiroshi

Nishiguchi in the National Institute of Science and Technology Policy (NISTEP) on Aug. 4, 2004 ("Effectiveness of Quasi-Zenith Satellite System as Viewed from National Strategy"). I am also indebted to those concerned in MIAC, MEXT, NiCT, ENRI, JAXA, ASBC for their kind offers of materials and useful discussion.

Notes

*1 One tenth second of latitude (north/south direction) is equivalent to approximately 3m on the earth's surface everywhere in the world, but a distance equivalent to one tenth second of longitude becomes shorter in high-latitude regions. The typical value in Japan is approximately 2m.

Acronyms and full spellings

- *ASBC* Advanced Space Business Corporation
- *DoD* Department of Defense
- *DOP* Dilution of Precision
- *ENRI* Electronic Navigation Research Institute
- *GPS* Global Positioning System
- *JAXA* Japan Aerospace eXploration Agency
- *METI* Ministry of Economy, Trade and Industry
- *MEXT* Ministry of Education, Culture, Sports, Science and Technology
- *MIAC* Ministry of Internal Affairs and Communications
- *MLIT* Ministry of Land, Infrastructure and Transportation
- *NAVSTAR* NAVigation System with Timing And Ranging
- *NiCT* National Institute of Information and Communications Technology
- *QZSS* Quasi-Zenith Satellite System
- *RAAN* Right Ascension of Ascendingl globe through which a satellite travels from south to north crossing the equatorial plane. Zero of right ascension is defined as the direction of the sun on Vernal Equinox Day.)

References

[1] "NAVSTAR satellites and six orbital planes": http://www.vxm.com/21R.111.html

[2] Document presented in #3 "Council for Science and Technology Policy , Conference on Positioning technology in Aerospace Exploitation: measurement branch, Positioning Subconference", Document No.3-3: "Public nature of positioning augmentation technology using Quasi-zenith satellite", Advanced Space business Corporation, Dec. 4, 2003 (in Japanese)

[3] "DARPA develops portable atomic clock," Government Computer News, April 17, 2003: http://www.gcn.com/voll_nol/daily-uptates/25302-1.html

[4] H. Nishiguchi, Lecture of National Institute of Science and Technology Policy (#142) delivered in National Institute of Science and Technology Policy: "Effectiveness of Quasi-Zenith Satellite System as Viewed from National Strategy", Sept. 2004 (in Japanese)

[5] Report #2015, "Technical conditions required to obtain transmitter position information from emergency call": a part of "A policy for Enhanced Emergency calls in Telecommunication enterprises", Telecommunication Council, June 30, 2004 (in Japanese)

[6] JAXA home page "High precision positioning system using Quasi-Zenith Satellite": http://qzss.jaxa.jp/

[7] ILS's Mission Overview "SIRIUS 1 Launch on the Proton Launch Vehicle": http://www.ilslaunch.com/launches/cbin/Mission_Overview/proton/Sirius1MissionOverview.pdf

[8] Takahashi: "Satellite orbits and their suited missions", Denpaken Kiho, Vol18, No.97, 1972 (in Japanese)

[9] National Institute of Information and Communications Technology home page "Time base management system" (in Japanese): http://www2.nict.go.jp/dk/c271/j/time/time.html

[10] Council for Science and Technology, Conference on Positioning technology in Aerospace Exploitation: measurement branch (#1), Document No.1-3: "Overview of Multifunctional Transport Satellite-based Augmentation System", Japan Civil Aviation

Bureau, Ministry of Land, Infrastructure and Transportation, Oct 28, 2003:
http://www8.cao.go.jp/cstp/tyousakai/cosmo/sokuihaihu01/siryo1-3.pdf

[11] Mizuma: “Technology development for Quasi-Zenith Satellite application on high speed traffic vehicles”, National Traffic Safety and Environment Laboratory, Apr. 14, 2004 (in Japanese)

[12] Forum for Social Basis in Enhanced Positioning (a Non-Profit Organization): “Proposals for Satellite Positioning System: Perspective from Private Sector”, Apr. 2004 (in Japanese)

[13] CHARTER “Interagency GPS Executive Board”, IGEB:
http://www.igeb.gov/charter.shtml

(Original Japanese version: published in January 2005)