Towards the Realization of Geo-Referencing Infrastructure for Dynamic Japan (GRID-Japan)

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Abstract

The recent change of the geodetic reference system of Japan from the Tokyo Datum to the Japanese Geodetic Datum 2000 (JGD2000) is an ongoing process to keep the system precise and up-to-date for the various demands of modern society. In the rapidly changing archipelago over tectonic plate converging zones and with the advent of an information society, future directions of the national geodetic reference system require special thought. A combination of GPS and information technology is now leading to the emergence of a Location Based Services (LBS) where positional information plays a key role to relate real space to cyberspace, opening up a geo-information society. Although the basic role of the geodetic reference system to control precise coordinates for surveying never change, a new role to support precise, real-time positioning should be developed. In addition, incessant crustal deformation in Japan should be properly handled by a semi-dynamic correction system for precise surveys with GPS. This paper presents a future design of the national geodetic reference system, introducing the concept of Geo-Referencing Infrastructure for Dynamic Japan (GRID-Japan). Through the partnership of local governments and the private sector, GSI will start the process of realizing the concept of GRID-Japan in the next ten years.

1. Introduction

In April 2002, Japan officially adopted a new geocentric reference system named Japanese Geodetic Datum 2000 (JGD2000), which is compliant with a modern global terrestrial reference frame. The Geographical Survey Institute (GSI) being the national mapping and surveying agency of Japan, has released Geodetic Coordinates 2000, i.e. the latest set of site coordinates of the national control points, based on JGD2000. This was a giant leap forward for the Japanese geospatial community, allowing GPS to be used as a major tool for surveying.

However, JGD2000 is not the end of the evolution of the Japanese geodetic reference system. The recent change in the geodetic reference system is part of an ongoing effort of GSI towards a ubiquitous positioning environment where anybody can access positional information of required accuracy, anytime and anywhere in Japan (GSI, 1993).

Since any geographic information contains positional data by definition, the coordinates of the geodetic control points are the most basic component of a Geographic Information Systems (GIS). In 2000, GSI proposed the promotion of "*Digital Japan*", a collection of digital geographic information concerning the national land as an infrastructure, to support the forthcoming information society in the 21st century (GSI, 2000). In this context, the geodetic reference system can be viewed as a grid of *Digital Japan*, enabling us to relate objects in real space to cyberspace by coordinates.

In addition, the Japanese archipelago is located in a tectonically active region, where crusts move and deform continuously, and earthquakes and volcanic eruptions occur occasionally. The fact that the geodetic control points can monitor crustal deformations denotes that the geodetic reference system is affected by the accumulation of crustal deformations over a long period.

To meet the wide requirements of the future geodetic reference system of Japan, GSI formulated an internal working group on the geodetic control system and proposed a vision to provide geo-referencing infrastructure, not only for surveying and mapping (including GIS and cadastre) but also for precise, real-time positioning and disaster mitigation by fully utilizing a nationwide GPS network (GSI, 2003a). This paper highlights the background, the necessity of and the roadmap to a Geo-Referencing Infrastructure for Dynamic Japan (GRID-Japan).

2. The current Japanese Geodetic System: JGD2000

To foresee the future, we have to begin by understanding the past and present. Here, we have a brief review of modern Japanese geodetic systems.

In Japan the geodetic datum was first determined about 100 years ago in the Meiji era when the modern survey was inaugurated to create detailed topographic maps of Japan (Komaki, 2004). Basically this Tokyo Datum was used for mapping, cadastre surveys and various public work projects as the legal reference to determine precise coordinates, up until March 31, 2002.

In April 2002, Japan officially adopted a new geocentric geodetic reference system following the revision of the Survey Act in 2001 (Matsumura et al., 2004). The revised act explicitly mandates the usage of longitude and latitude, based on a global geocentric reference system, for public surveys conducted or supported by the public sector.

Space geodesy played a key role in establishing the new reference system (Murakami and Ogi, 1999). Horizontal coordinates of all the control points in Japan were re-computed, based on the latest survey results, including those from the nationwide continuous GPS observation network (GEONET) and the Very Long Baseline Interferometry (VLBI) network.

The new set of coordinates, named Geodetic Coordinates 2000, compliant to the modern global reference frames such as the International Terrestrial Reference Frame (ITRF), have enabled the usage of GEONET as the legal control points for various public surveys in Japan.

The enforcement order of the Survey Act defines the datum origin of JGD2000 on the ground. This means that JGD2000 is a static system, fixed on the Japanese archipelago. The horizontal coordinates of the datum origin were given on the ITRF94 as at January 1, 1997. In other words, the epoch of JGD2000 is 1997.0 (Tsuji and Matsuzaka, 2004).

Along with the horizontal datum redefinition, re-adjustment of the vertical control network was also conducted. Orthometric heights of benchmarks have been newly computed, using the latest leveling and gravity data (Imakiire and Hakoiwa, 2004). Geoidal heights computed from the hybrid geoid model GSIGEO2000 that uses both gravimetric and GPS/leveling data complete Geodetic Coordinates 2000 (Nakagawa et al., 2003).

In summary, JGD2000 refers to the entire current Japanese geodetic reference system, including the horizontal and vertical systems, and Geodetic Coordinates 2000 in a broader sense include:

1) Horizontal coordinates of the national control points compliant to ITRF94 with Epoch 1997.0;
2) Orthometric heights of the national leveling points, and;
3) the GSIGEO2000 geoid model.

Table 1 shows the number of national control points as at April 1, 2002. The set of site coordinates of these actually realizes JGD2000 on the ground, i.e. precise positions in JGD2000 can be obtained by making a relative survey between the point of interest and the control points and by calculating the coordinates of the point, based on those of the control points.

Table 1 Number of national control points as of April 2002.

Monuments	Numbers	Breakdown		Mean Distance
VLBI stations	4	Tsukuba, Shintotsukawa, Aira, Chichijima island		1,000km
GPS-based Control Points	1,054	GEONET stations	947	25km
		GPS Fixed points	107	
Triangulation Points	102,558	1st order	973	25km
		2nd order	5,056	8km
		3rd order	32,723	4km
		4th order	63,806	2km
Leveling Points (Benchmarks)	20,653	Primary	80	150km
		1st order	15,543	2km
		2nd order	4,543	2km
		3rd order	487	2km
Others	6,185			
Total	130,454			

Table 2 compares the statuses of the Japanese geodetic reference system before and after April 1, 2002. The century-old local geodetic reference system is re-constructed as the precise global geocentric reference system.

Table 2 Statuses of the Japanese geodetic reference system before and after April 1, 2002.

Name	Tokyo Datum	JGD2000
Effective period	Before March 31, 2002	After April 1, 2002
Reference ellipsoid - radius (semi major axis) - flattening - origin	Bessel 6377397.155 m 1/299.152813 Not geocentric	GRS80 6378137 m 1/298.257222101 Geocentric
Geoid and ellipsoid	Reference ellipsoid considerably deviates from the geoid in Japan.	New Japanese Geoid model (GSIGEO2000) is released.
Height system	Model gravity values are used instead of real data for height determination.	Real gravity values are used to determine orthometric heights.
Precision	Precision of GPS surveys exceeds that of the century-old geodetic reference system.	New Geodetic Coordinates 2000 adjusted with the latest data are released.

Since April 2002, Geodetic Coordinates 2000 are widely used as the reference of coordinates for public surveys in Japan without confusion, due to intense public relations before the adoption of JGD2000.

To enhance crustal deformation monitoring by GPS, the number of GEONET stations was expanded to 1,200 at the end of 2002. The real-time GPS data collected from GEONET for kinematic analysis of crustal deformations are also provided to the public though private sector services, in real-time.

An information service on control points through the Internet has also begun. A description of control points can be seen on the GSI web page since 2000. The page was accessed more than one million times per year, both in 2000 and 2001.

In summary, the Japanese geodetic reference system is in good shape at the moment.

3. Driving forces beyond JGD2000

Although JGD2000 solved many of the Tokyo Datum problems, further efforts beyond JGD2000 are required to adequately cope with the following natural and social factors surrounding JGD2000.

3.1 Accumulating crustal deformations

Since Japan is located in one of the most tectonically active regions in the world, the effect of crustal deformations should be explicitly handled, especially for GPS surveys that form long baseline networks.

3.1.1 Deviations from ITRF

JGD2000 originates from the ITRF94 coordinates of three VLBI stations in Japan at the epoch 1997.0. Since it is a static datum, as is usual for national geodetic reference systems, Geodetic Coordinates 2000 of each control point are constant in time. Thus they gradually or spontaneously deviate from real positions, due to secular plate motions or episodic crustal deformations associated with earthquakes or volcanic activities. Fig. 1 shows an accumulation of horizontal crustal deformations observed by GEONET during the period January 1997 to July 2001. This can be viewed as the deviations of real positions from Geodetic Coordinates 2000 in the intervening 4.5 year period. Most of the stations have velocities of about 2-5 cm/year with respect to ITRF and some stations in the southwest islands have shown movements greater than 20 cm. Note that exceptionally large displacements of over 50 cm came from volcanic activity.

Since nearby stations show similar trends, the displacements will not directly cause a serious problem for surveying. But in the long run, the deviation will be detectable with the current precision of GPS point positioning and an entire revision of JGD2000 should be considered.

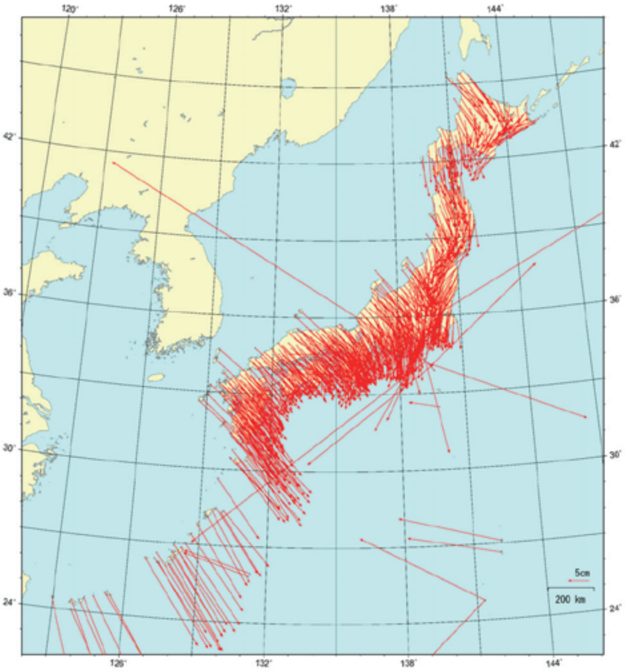

Fig. 1 Displacement of GEONET stations from January 1997 to July 2001 in ITRF94, based on the method by Hatanaka (2002).

3.1.2 Deformation of network

Fig. 2 shows the horizontal principal strain rates of Japan, obtained by smoothing and interpolating the velocity of GEONET. In extensive areas, the absolute values of strain rates exceed 0.1 ppm/year. Another study based on re-surveys of triangulation points with a density higher than GEONET, shows slightly larger strain rates during the past 100 years, i.e. 0.1-0.3 ppm/year in most regions and up to 0.6 ppm/year in the Shikoku, southern Kanto and Fukui regions (Ishikawa and Hashimoto, 1999).

On average, horizontal strain accumulates by about 0.2 ppm/year all over Japan. Since Geodetic Coordinates 2000 are fixed, to be constant at the epoch 1997.0, the relative precision of the geodetic network degrades by about 0.2 ppm/year.

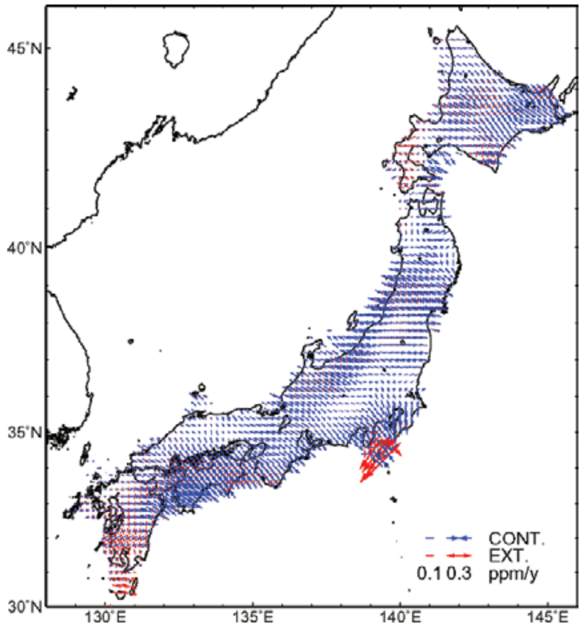

Fig. 2 Horizontal principal strain rates obtained by smoothing the GEONET data from June 1996 to May 2000, based on the method by Sagiya (2000). CONT denotes magnitude and direction of contraction of the crust, whereas EXT denotes those of extension.

These deformations are negligible for surveys that use a total station (TS)* with nearby control points. For example, a 10 year accumulation of 0.2 ppm/year deformation amounts to only a 2 mm error for 1 km baselines. However, for GPS surveys that use GPS-based control points typically about 10 km away, the same rate could result in a 2 cm error over 10 years. These are not negligible, considering the precision of current GPS relative positioning. Therefore, correction of crustal deformations is a mandate for GPS surveys.

3.2 Trends in technology and society

Key technologies often change the trend in our society, sometimes demanding new functions for old social infrastructure, such as the geodetic reference system.

3.2.1 Future of GPS and satellite positioning system

The United States Government states that it recognizes the key role of GPS as part of the global information infrastructure and takes seriously its responsibility to provide the best possible service to civil and commercial users worldwide (U.S. Coast Guard, 2003). This statement is strong support for the current wide usage of GPS in surveying.

The U.S. Department of Defense plans modernization of GPS signals in the next decade (Fontana et al., 2001). It includes the provision of a new L5 frequency and adding the C/A code to the L2 band. Although this will open a new and enhanced possibility for GPS, extreme care should be taken with its implementation, because GPS is now a major tool for surveying. For example, receivers and antennas for GPS surveys will have to be upgraded to benefit from the GPS modernization, requiring a certain cost. Note that GEONET stations are not immune to this modernization.

In 2001, the U.S. Department of Transport (DoT) issued a report on the vulnerability assessment of the transportation infrastructure that relies on GPS, recommending a backup system for critical applications (John A. Volpe National Transportation Systems Center, 2001). As an example of the vulnerability of GPS, a commercial jammer that transmits received GPS signals with a certain time delay is mentioned (Lemmens, 2002).

Although the proposed European Satellite Navigation System, Galileo, or other Global Navigation Satellite Systems (GNSS) might serve as a backup for GPS in future, maintenance of the conventional geodetic network on the ground is necessary, considering the

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* TS: A surveying instrument that combines a theodolite for measuring angles and an electromagnetic distance meter.

importance of surveying and crustal deformation monitoring to secure people's lives, safety and property.

A U.S. commercial company is providing a global satellite-based augmentation system, claiming a capability of real-time decimeter positioning anywhere in the world (http://www.navcomtech.com/home.cfm). As the precision of such global DGPS goes up, their application to national surveys might become an issue.

3.2.2 Emergence of Location-Based Services (LBS)

The combination of mobile computing and global navigation systems has brought about a new application called Location-Based Services (LBS). It is expected that positional information will play a key role in relating real space to cyberspace, thus opening a geo-information society. For example, phone companies are providing location-based information, using a cellular phone with GPS on board. Emergency and tracking services are also provided, based on this. As their precision increases, consistency with existing geographic information will be required.

3.3 Voices from users

To understand users' demands and reality, GSI conducted 12 interviews with local governments, public corporations and private companies that use the geodetic reference system (GSI, 2003a). The results show a wide range of demands for a modern reference system, including the following opinions:

- For disaster monitoring, real-time official coordinates of GEONET are necessary;
- Conventional control points suited to TS are still required in urban areas where GPS is not efficient under poor satellite visibility;
- Some triangulation points in mountainous areas are not suitable for GPS surveys, due to poor satellite visibility and difficulty of access to the points.

According to the surveillance on public surveys, the public sector performed 1,043 survey projects to establish 61,078 control points in 2001 (GSI, 2003b). Fig. 3 compares the usages of GPS and TS in those projects. For large scale projects that establish 1st or 2nd class public control points, GPS is frequently used. But for all projects, including lower class surveys, TS is slightly more popular than GPS. This suggests that users prefer TS for surveying a dense network in urban areas.

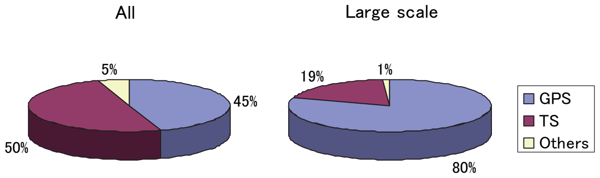

Fig. 3 Ratio of GPS and total stations (TS) used in the public surveys in 2001

4. Design of a future geodetic reference system

In the previous chapter, we have seen the driving forces urging further evolution of JGD2000. Here we discuss what an ideal geodetic reference system should be in the future.

4.1 Basic functions as survey reference and crustal deformation monitoring

Historically, the geodetic reference system has been maintained to control positions for various surveys, including mapping. Based on the national control points maintained by GSI, local governments conduct public surveys to establish local control points and/or large scale maps such as cadastre. Through this hierarchy, accuracy and consistency of coordinates of geographic information are assured. This is what the Survey Act requires of the geodetic datum as a survey reference and this function of the geodetic reference system will never change.

The second function is the monitoring of crustal deformations. If geodetic surveys between the same control points are repeated, one can obtain the temporal change of the baseline length and components, i.e. the crustal deformations in the area. The control points have been playing a vital role in disaster mitigation as a reference point for monitoring crustal deformations associated with earthquakes and volcanic activity. The 1st, 2nd, and 3rd triangulation points established for topographic mapping, mainly in the Meiji era (1868-1911) have been re-surveyed by electromagnetic distance measurement and GPS, revealing crustal deformations in the past 100 years. Now, the GPS-based control points that form GEONET can repeat precise surveys, once per second.

These two functions, i.e. the survey reference and the crustal deformation monitoring, are actually two sides of the same coin in Japan and will continue to be the central role of the geodetic reference system in future.

4.2 New function to support LBS

With the recent introduction of network-based, real-time, kinematic GPS methods, the border between navigation and surveying seems to become ambiguous.

However, we see one important difference in their priorities. Surveying pursues accuracy at the expense of time while navigation pursues real-time solutions at the expense of accuracy. This comes from a tradeoff between the time required to obtain positions and the accuracy of those positions. For example, every survey includes the averaging of independent observations and network adjustments with several control points in order to assure its accuracy, consuming a certain amount of time. In navigation, it is necessary to know current positions immediately while moving.

Therefore, surveyors seek real-time surveying techniques while maintaining accuracy and navigators seek precise navigation techniques in real time. Those two meet in the field of positioning, where the new business of LBS is going to blossom (Fig. 4).

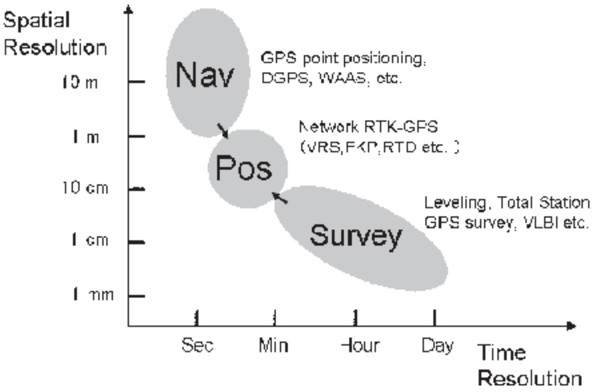

Fig. 4 Schematic diagram showing relationship between surveying (Survey) and navigation (Nav). Positioning (Pos) here denotes precise navigation or real-time surveying.

To secure consistency of geographic information in the new field of precise navigation, or real-time surveying, surveying that places a priority on accuracy should provide the reference. For example, if the reference system of LBS is based on the national geodetic reference system, consistency between LBS services and existing geographic information is assured and leads to better customer satisfaction.

The geodetic reference system has been serving as a reference for surveys. But the trends in technology and society require a wider role to provide reference to precise navigation as well. In other words, the geodetic reference system should evolve into a geo-referencing infrastructure. Table 3 summarizes the functions required for a geo-referencing infrastructure.

Table 3 Functions of geo-reference infrastructure

Functions	Priority	Required accuracy	Objectives	Upper objectives
Survey reference	Local consistency	1 – 10 cm	To secure accuracy of public surveys	Protection of property
Crustal deformation monitoring	Temporal continuity	1-10 mm	Prediction of earthquake and volcanic activities	Protection of life
Position representation	Uniqueness	Several m (w.r.t.* geocenter)	Claim of national lands, Base of several laws	National security, Base of administration
Assistance to LBS	Real-time	10 cm – 1 m (w.r.t large scale maps), Several m (w.r.t. small scale maps)	Location based services, Navigation	Promotion of economic and social activities
Location reference	Visible on aerial photos or satellite images	Ditto	GIS	

* with respect to

4.3 Robust system through synergy

To securely provide necessary functions of geo-reference infrastructure in the long-term, a combination of several geodetic techniques and networks is desirable.

4.3.1 GPS with VLBI

For the maintenance of the global reference system, space geodetic techniques that can measure continental distances to within a few centimeters of accuracy are mandatory. Japan adopts the global reference system consistent with the ITRF maintained by the International Earth rotation and Reference systems

Services (IERS). IERS combines results from various space geodetic observations such as VLBI, GPS, and Satellite Laser Ranging (SLR) to yield the ITRF. By the combination of different techniques, accuracy of each result can be properly evaluated.

Among the space geodetic techniques, VLBI is unique in providing the most stable reference system and being sensible to the fluctuation of the earth's rotation (UT1), because it uses natural radio sources from outside our galaxy (Tsuji et al., 2005).

To secure the national geodetic reference system, GSI should continue contributing to IERS through international VLBI and GPS observations. The domestic network of VLBI stations should also be maintained because it is one of the few tools that can evaluate the accuracy of GEONET solutions.

4.3.2 Conventional and GPS-based control points

Although GPS has become a major tool for geodetic surveying, TS sometimes provides more efficient performance for detailed surveys in urban areas. Together with GPS modernization and vulnerability issues, maintenance of the conventional network is also necessary.

1) Restoration of land parcels

   Public surveys, including cadastre, refer to the national control points. In cadastre, restoration of land parcels is of importance, requiring a millimeter level consistency between neighboring control points. In a rapidly deforming Japan, we need dense networks to keep this local consistency. For example, GPS-based control points with a mean distance of 20-25 km, experience a 5 cm horizontal distortion over 10 years, whereas 4th-order control points (mean distance: 2 km) experience a 4 mm distortion over 10 years. Locally dense control points can assure the restoration of borders or points from coordinates, even if complex crustal deformations occur.

2) Long-term stability of the reference system

   Because civil and commercial usage of GPS depends on U.S. policy, we should bear in mind the possibility of degradation, termination, or upgrading of the system that may cause obsolescence of user equipment. The U.S. DoT also recommends a backup system for critical applications (Section 3.2.1). The conventional control points can serve as a backup for GEONET in rare case of GPS outage for surveying.

3) Limitation of satellite surveying techniques

   Since GPS surveying requires visibility to satellites in the sky, it is difficult to conduct GPS surveys in urban or mountainous areas, due to obstruction by buildings etc. or topography. In such areas, surveying with TS might be an alternative and conventional control points can support such surveys.

4) Deformation monitoring on a long-term basis

   GPS continuous observations have been recording precise and detailed crustal deformations in Japan since the mid-1990s. Re-surveys of selected conventional control points can detect crustal deformations that have occurred since about 100 years ago. These results, with a different time scale, are complementary to researching long-term crustal deformations in Japan.

The above discussions hold mainly for horizontal control points. Although GPS height measurements with a geoid model can give orthometric height with a 10 cm level of precision, the leveling point network should be maintained as a vertical reference with a millimeter level of accuracy.

One might think further evolution of satellite point positioning will make a ground-based national geodetic network obsolete. However, this is not the case. Suppose we have an ultra-GPS that can yield point positioning results in ITRF with 1 cm accuracy in real-time. We still need control points on the ground to detect the movement of the ground, because people living on the earth are interested in features on the ground that move with secular plate motion and episodic crustal deformations with tectonic events. Ultra-GPS may tell you the exact longitude and latitude of the receiver on that day in ITRF, but that alone will not allow any referencing to existing geographic information. Of course, we can use such ultra-GPS to conduct efficient surveys of the control points.

4.4 Reference in a dynamic and deforming Japan

Continuous or repeated surveys of control points reveal crustal deformations in Japan. At the same time, information of crustal deformations is mandatory for the maintenance of the geodetic reference system. Here we present a strategy to realize a precise reference system in a deforming Japan.

4.4.1 Deformation monitoring by GEONET

GEONET, which covers the whole of Japan with about 1,200 GPS-based control points, is a powerful tool for monitoring wide-area crustal deformations. This is one of the densest GPS arrays in the world and the number of stations is probably reaching the upper limit, considering their maintenance costs. Expansion of GEONET should focus on areas where large tectonic events are expected to occur, such as volcanic or pacific coast areas. More emphasis should be placed on system refinement to allow more rapid and reliable detection of crustal deformations.

4.4.2 Necessity of crustal deformation correction

When using GEONET for GPS surveys, we should bear in mind that we are using relatively remote reference points, typically 10 km apart. With this range, correction of secular crustal deformations will be necessary to keep consistency with nearby conventional control points. If deformations are not corrected, positions determined from GPS-based control points may lose consistency with those of neighboring conventional points. This problem will be serious as time goes by, beyond the epoch 1997.0 and as the distance from GPS reference points increases.

At GPS-control points, the accumulation of crustal deformations are monitored continuously, so deformation corrections are entirely possible. However, we also need the deformation data at the very points where we want to survey. Here we need re-surveys of a denser geodetic network.

4.4.3 Re-surveys of conventional control points

Past geodetic surveys have revealed the complex nature of crustal deformations in Japan. GPS-based control points alone do not provide enough spatial resolution of crustal deformations. Thus, we need re-surveys of the conventional control points between GPS-based control points to create a deformation model with 1 cm accuracy over a 10 km distance.

Our strategy is to select 2,400 triangulation points from the 1st to 3rd triangulation points and repeat GPS surveys of these every 10 years. The reason for this number is as follows:

1) The average crustal strain rate in Japan is 0.2 ppm/year;
2) The precision target of selected control points is 1 cm, thus error allowance is 2 cm;
3) We can keep crustal deformation errors to less than 2 cm if we repeat surveys every 10 years for 10 km baselines;
4) We can cover the whole of Japan with 10 km spacing of about 3,600 points, considering the 1st and 2nd order triangulation network does so with 6,000 points with 8 km spacing;
5) If we subtract the number of GPS-control points from 3,600, we get 2,400.

Of course, if we increase the number of GPS-control points to 3,600, we can cover the whole of Japan with a 10 km spacing. But that would require maintenance costs that exceed the budget of GSI for all geodetic surveys. Therefore, a combination of GPS-based and conventional control points is a realistic and cost-effective approach.

4.4.4 Methods of deformation correction

1) Episodic deformation from tectonic events

In case earthquakes or volcanic activity cause crustal deformations that exceed tolerance limit of the reference system, Geodetic Coordinates 2000 of control points in the affected region should be revised as soon as possible. To do so, we need re-surveys of conventional control points in the region. The affected region can be estimated from the analysis of GPS-control points.

2) Secular deformation from plate motions

As stated before (Section 3.1), the mean velocity of the Japanese archipelago with ITRF is 2-5 cm/year and the strain rate is 0.2 ppm/year. If we suppose the precisions of point and relative positioning of GPS as 5 m and 1 ppm respectively, a GPS surveyor will find the distortion of JGD2000 in just 5 years, whereas point positioning users would need 100 years to detect the deviation of JGD2000 from ITRF.

From an academic point of view, treating coordinates as a function of time, like ITRF, is the simplest solution. However, considering the vast number of users in cadastre and land registration, this dynamic datum is too early to introduce, because it will bring confusion to the concept of real estate, thus impeding the Japanese property market.

To cope with the complex nature of crustal deformations, as well as with social demands from general users, the adoption of a semi-dynamic system is considered to be an adequate option. The semi-dynamic datum is a static datum with fixed coordinates, but accounts for accumulation of crustal deformations by applying epoch reduction to observed survey data, based on an authorized velocity or deformation model.

Such a system is already implemented as New Zealand Geodetic Datum 2000 (Grant and Blick, 1998). A simplified observation equation using a velocity model is:

$$\mathbf{O}-(\mathbf{V}_{\mathrm{B}}-\mathbf{V}_{\mathrm{A}})(t-t_0)=\mathbf{B}-\mathbf{A}\ ,$$

for an observed baseline vector $\mathbf{O}$ between points A and B, where t is the time of observation, t_0 is the epoch of the datum, $\mathbf{V}_{\mathrm{A}}, \mathbf{V}_{\mathrm{B}}$ are model velocities at A and B, and $\mathbf{A}, \mathbf{B}$ are position vectors of A and B, respectively.

An authorized deformation model can be constructed by smoothing and interpolating deformation fields of GPS-based control points and selected 2,400 conventional control points.

5. GRID-Japan concept

Discussions in the previous chapter led to identifying the necessity of evolving the geodetic reference system into a geo-referencing infrastructure that supports surveying, crustal deformation monitoring, GIS, LBS and so on.

5.1 What is GRID-Japan ?

Fig. 5 illustrates the evolution path of the Japanese geodetic reference system. Our final goal is to realize a ubiquitous positioning environment where anybody can access positional information of required accuracy, anytime and anywhere in Japan, as formulated in 1993.

Towards this goal, we plan to implement necessary measures and develop new technologies in the next decade, under the concept of Geo-Referencing Infrastructure for Dynamic Japan (GRID-Japan).

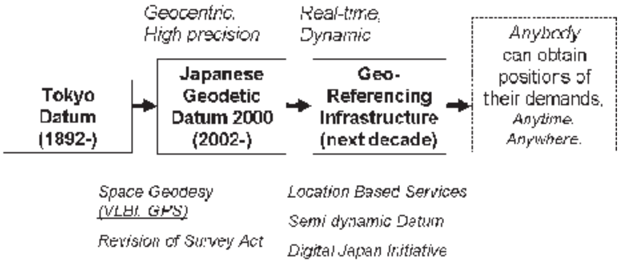

Fig. 5 Evolution of Japanese geodetic reference system

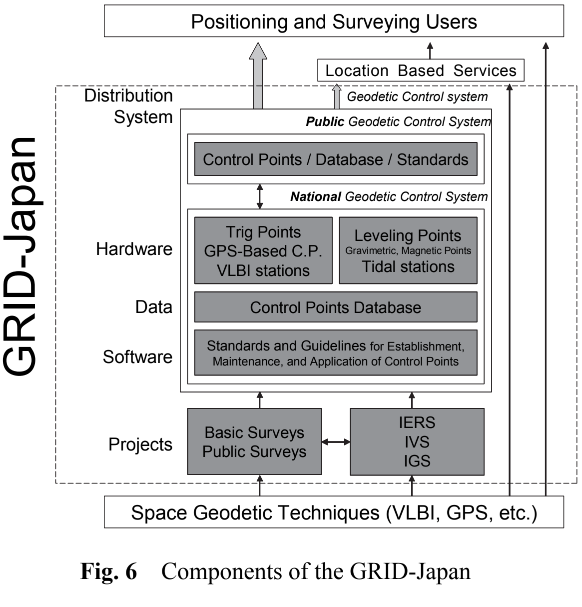

Fig. 6 Components of the GRID-Japan

Fig. 6 shows the major components of GRID-Japan. It is composed of:

1) national and public geodetic control points maintained by GSI and local governments;
2) a positional information database that include

coordinates of control points, records of surveys at each point, crustal deformation models, and so on;

3) standards and guidelines concerning control points;
4) domestic and international surveying projects that support the control systems, and;
5) a data distribution system to general users.

The Survey Act allows GSI to collect survey data conducted by the public sector. By providing adequate standards and guidelines, sharing of positional information will be possible through a virtual database system on the Internet.

Note that the concept includes a commitment to international projects such as IVS and IGS for VLBI and GPS observations respectively, in which GSI participates.

5.2 Outcome targets

GSI's mission is to provide a global, real-time, and dynamic geo-referencing infrastructure for those who needs positional information anytime and anywhere in a dynamic and deforming Japan. To achieve this mission, we set priorities on the following areas as the outcome targets for the next decade:

1) Near real-time monitoring of crustal deformation in Japan with 1 mm to 1 cm precision in areas that are prone to tectonic events in future;
2) Geodetic control that supports surveying users with 1 to 10 cm precision on land, even after major earthquakes;
3) Support of low-cost real-time positioning with 0.1 to 1 m precision on land and near the coast, including major underground areas, through public and private partnership;

The last target may require some explanation. From May 2002, GSI has been providing real-time raw data of GPS-based control points to the public and some private companies are providing value-added services that enable real-time kinematic positioning. This could be a basis for low-cost real-time positioning using GPS-based control points in future. Considerable R&D will be necessary for seamless positioning, including underground positioning.

5.3 For implementation

To realize the concept of GRID-Japan, further consideration for specifics of the components and discussions among related bodies will be necessary.

However, the concept of GRID-Japan is already formulated in the long-term plan of basic surveys that spans the period 2004 to 2013 (GSI, 2005). GSI will promote the necessary steps to achieve the goal of ubiquitous positioning through the implementation of the long-term plan.

Of course, GSI alone can not achieve the outcome targets stated above. Collaboration with local governments and the private sector is essential to establish GRID-Japan in the future.

6. Conclusions

GSI will provide a Global, Real-time, Intelligent and Dynamic geo-referencing infrastructure for those who need positional information, anytime and anywhere, with the required precision, in Japan. This is another description of GRID-Japan. Through the implementation of the long-term plan of basic surveys with public/private partnership, GSI will promote the realization of geo-information society in Japan.

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