国土地理院技術資料 A6-No.84
ISSN 2185-3681

BULLETIN OF THE GEOSPATIAL INFORMATION AUTHORITY OF JAPAN

December, 2015

Vol.63

GEOSPATIAL INFORMATION AUTHORITY OF JAPAN
MINISTRY OF LAND, INFRASTRUCTURE, TRANSPORT AND TOURISM

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GEOSPATIAL INFORMATION AUTHORITY OF JAPAN
MINISTRY OF LAND, INFRASTRUCTURE, TRANSPORT AND TOURISM

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An effective synchronization method of GSI Tiles using a GSI Tile List

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(Published online: 27 October 2015)

Abstract

"GSI Tiles" are tile-based geospatial information for web maps provided by the Geospatial Information Authority of Japan (GSI) under the standardized terms of use of the Japanese Government. GSI Tiles contain official topographic map data maintained under the Survey Act, and also more than 1,000 layers, covering topographic maps, aerial and satellite images, thematic maps, and disaster information. While these data are typically used for web maps such as the "GSI Maps" run by GSI, they are also available for download, and it has been decided that the same server which is used to run "GSI Maps" is to be used to provide these data for download. To keep the server highly available, an effective synchronization method for GSI Tiles has been developed.

To fulfill this purpose, the concept of "GSI Tile Lists" was proposed. A GSI Tile List contains metadata for the files for a layer of GSI tiles. File paths, modification times (mtime), size, and MD5 message-digests are recorded in a GSI Tile List. The download and synchronization of the GSI Tiles can be made more effective by using a GSI Tile List. GST Tile Lists are updated weekly to reflect the rapid update of the topographic data of GSI. A reference implementation of the GSI Tiles downloader using GSI Tile Lists (qdltc) has been developed and published via a social coding site. A layer of topographic map data covering the whole area of Japan, consisting of 50 million tiles, can be downloaded within around a week. A weekly update of these topographic data, consisting of tens of thousands of tiles, can be downloaded within around 7 hours.

1. Background

The Geospatial Information Authority of Japan (GSI) publishes more than a thousand layers of tiled geospatial data called "GSI Tiles". GSI Tiles contains the latest products of the topographic surveys conducted since the 1880s. GSI Tiles also contain orthophotos, thematic maps, and disaster information.

The Information Access Division also operates a web map of GSI called "GSI Maps" (Geospatial Information Authority of Japan, 2015a). GSI Maps functions as a showcase of the application of GSI Tiles. GSI Maps has been continuously in operation for more than 12 years, if we take the preceding service, Digital Japan Portal, started on July 15, 2003, into account. The emphasis is always on availability of the service, aiming at 24-hour 365-day operation from the beginning.

GSI provides a view of Japan to the nation of Japan and also to the globe, by providing GSI Tiles and GSI Maps.

As of July 2015, the Information Access Division considers the following three policies important for promoting the use of GSI Tiles: open data policy, open source policy, and open innovation policy.

The open data policy promotes wider use of the GSI Tiles by the adoption of terms of use which are easier to understand. GSI has enacted the GSI Contents Terms of Use following the Japanese Government Standard Terms of Use (version 1.0) on September 30, 2014. The terms of use for the GSI Tiles are updated by the GSI Contents Terms of Use on the very day of enacting the terms of use.

Because the terms of use cover only the copyright, naturally the procedure enacted in the Survey Act is

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required. The Information Access Division keeps contact with developers who use GSI Tiles to lower the difficulty of how they follow the procedure.

The open source policy means the use of open source software and the release of open source software in GSI Maps (Geospatial Information Authority of Japan, 2015b). The aim of the policy is to share functions and technologies fundamentally necessary for the use of GSI Tiles, and raise the minimum technological expertise of the industry.

Open innovation policy is to pursue innovative results by related parties by seeking collaboration with external bodies. We see the idea of open innovation is important especially because there are a variety of applications of geospatial information. A set of specialized skills is necessary for each field of application. Collaboration with parties for each field of application is necessary.

In order to realize an open innovation policy, the functions of GSI Maps have gradually been modularized, taking the various existing standards into account. With modularization, parties can take some modules for their application, or they can replace some modules for their application. One example of such modularization is the adoption of slippy map tilenames (XYZ) on 30 October 2013. By adopting a well-used tile-naming standard, more open competition for software can be initiated. In other words, the applicability of the GSI Tiles is widened. The number of desktop applications and mobile applications got significantly bigger. Another benefit of adopting slippy map tilenames is the successful migration from OpenLayers 2 to Leaflet in GSI Maps on 8 July, 2015.

The Information Access Division has also operated the “GSI Maps Partner Network” since July 11, 2014. The network consists of developers who use or plan to use GSI Tiles for their work. 121 parties have already joined as of 30 June, 2015. They contribute to the “GSI Maps Partner List”, a collection of information about the application of GSI Tiles. In order to promote sharing the latest information, a conference for the GSI Maps Partner Network has been held three times, in November 2014, February 2015 and June 2015.

2. Challenges

The standard map of GSI Tiles was officially announced as an authoritative basic survey result on 1 July, 2014. GSI takes responsibility for keeping these survey results up to date, and takes responsibility for providing the data to the public. The server for GSI Maps remains the sole channel for providing GSI Tiles to the public. This has led to an urgent need to provide GSI Tiles more effectively, especially for usage where bulk downloading and/or frequent updates are required.

There were risks to the availability if we did not take any action to provide ways to download and synchronize GSI Tiles data.

2.1 Technical details

While the map-tiling method is a cost-effective way to access data at a specified geographic location, the way to download a tile-set of some volume is not very obvious.

A list of tile files with metadata for timeliness or uniqueness would be useful for downloading such data more effectively. We call such a list the “GSI Tile List”.

There are more than 50 million tile files for a single layer of a standard topographic map. The total number of GSI Tiles is about 200 million.

We use a content delivery network (CDN) to provide faster access to the tile data. It was agreed that to be cost-effective, the same CDN must be utilized for bulk download and rapid synchronization.

It was agreed that the frequency of the synchronization must be up to users at the downloading side, because timeliness requirements for applications will vary.

Because the announcement has already been made, it was agreed that the release of the method must be as soon as possible, especially for developers. For this reason, it was agreed that the data production process and data uploading process must not change for the development of the method.

3. GSI Tile List

3.1 The reason GSI Tile List is developed

The GSI Tile List is a CSV file which contains metadata for each tile file stored on one layer at the server.

Japan consists of a long archipelago. The HTTP access log for the tile server indicates that there have been a lot of requests for sea areas where no tile data exists. In the case of the Japan area, a "brute force" attempt to download the tile data is not effective. This ineffectiveness is considered harmful to both sides of the HTTP request. This is why the GSI Tile List was developed.

3.2 Specifications for GSI Tile List

When the template URL of the tile-set is http://server/t/{z}/{x}/{y}.ext , the URL of the GSI Tile List must be http://server/t/mokuroku.csv.gz as default. The format of the data is gzipped CSV.

As of July 2015, the format of the CSV data is:

[path],[modification date],[size],[MD5 message-digest]

The part for "{x}/{z}/{y}.ext" of the URL is defined as [path] field for the CSV data. The URL of the tile data would be http://server/{t}/[path].

The [modification date] is an integer number which represents UNIX epoch time. The unit for [size] is bytes.

The [MD5 message-digest] is the MD5 hash value of the specified tile data (Rivest, 1992). The reason for using the MD5 message-digest is to skip "phony updates," updates where only the modification time has changed, not the content. This occurs rather frequently because the rendering of the tiles runs for a specified area where only several parts are actually modified.

These specifications are available at a social coding site (Geospatial Information Authority of Japan, 2015c).

The size of mokuroku.csv.gz for the standard topographic map data (around 50 million tiles, around 350GB) is around 1.2GB when packed in a csv.gz file.

3.3 mokuroku generator

The tool to generate mokuroku.csv.gz at the server side is also released at a social coding site (Geospatial Information Authority of Japan, 2015d). This tool takes layers*.txt file (Geospatial Information Authority of Japan, 2014) on the server and scans the file system to generate mokuroku.csv.gz for each layer.

3.4 A viewer for GSI Tile List

A viewer for GSI Tile List, sl.rb, is available at the social coding site (Geospatial Information Authority of Japan, 2015e). The following is an example of viewing the current status of the GSI Tile List in the server.

```
$ ruby sl.rb
○ ,std,2015-07-19 12:17:36,1.21 GB, 標準地図
○ ,pale,2015-07-14 12:13:23,1.21 GB, 淡色地図
○ ,blank,2015-07-14 13:15:27,9.12 MB, 白地図
○ ,english,2015-07-14 13:25:46,602 KB,English
...
```

The following is an example to get a list of URLs of the GSI Tile List.

```
$ ruby sl.rb --mokuroku_urls
http://cyberjapandata.gsi.go.jp/xyz/std/mokuroku.csv.gz
http://cyberjapandata.gsi.go.jp/xyz/pale/mokuroku.csv.gz
http://cyberjapandata.gsi.go.jp/xyz/blank/mokuroku.csv.gz
http://cyberjapandata.gsi.go.jp/xyz/english/mokuroku.csv.gz
...
```

4. qdltc – a reference implementation of a downloader

An effective synchronization method of GSI Tiles using a GSI Tile List is proposed in this section. A reference implementation of this method, qdltc (Queued DownLoader with Timeline backup and MD5 message-digest Cache) is available as open source software (Geospatial Information Authority of Japan, 2015f).

4.1 Filter tiles by checking MD message-digest

When there is a local copy of the tile specified in a line of mokuroku.csv.gz, the MD5 message-digest of the local copy is calculated. If the MD5 message-digest of the local copy is the same as the MD5 message-digest written in the mokuroku.csv.gz, nothing needs to be done and thus the line of the mokuroku.csv.gz is skipped (Fig-1).

By checking not the modification time (mtime) but the MD5 message-digest, we can also skip "phony updates" which constitute a significant portion of the update, at least under the current production process of GSI Tiles.

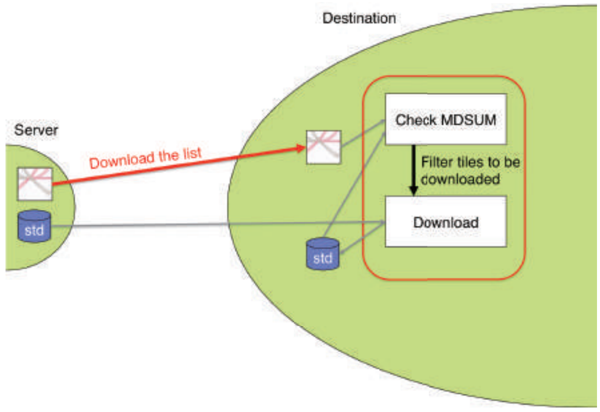

Fig. 1 Filter tiles by checking MD5 message-digest

4.2 Use of queue

Parallel and asynchronous HTTP requests are commonly used in web browsers. To take the same measure within this tool, the process to check MD5 message-digest and the process to download and write the tile data are separated as different threads. A queue is inserted to connect the MDS5SUM check thread and parallel download threads (Fig-2). The default number of download threads is set to 8, and the depth of the queue is set to 200. Where the Internet connection is not very good, the number of download threads can be set bigger, such as 32. The depth of the queue can be several tens of thousands, especially for less significant updates.

By introducing a queue, the performance of the tools got a few times faster.

4.3 Backup of old files

The process to backup old local copy is introduced. The old local copy {z}/{x}/{y}.ext is moved to bak/{z}/{x}/{y}.{yymmdd}.ext, where the modification date of the old local copy is {yyyymmdd}, so backups of old local copies will be accumulated.

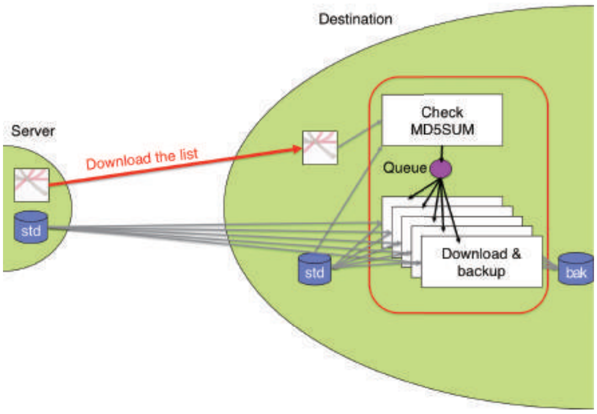

Fig. 3 Backup of old files

4.4 Caching local MD5 message-digest

The first step of the synchronization is to calculate the MD5 message-digest of the local copy. This is performed for tile files which have not been updated, which comprises the majority of the tile-set. To eliminate this, caching of the local MD5 message-digest

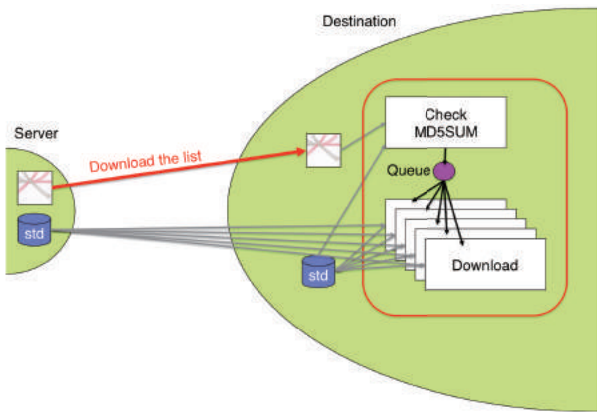

Fig. 2 Use of queue

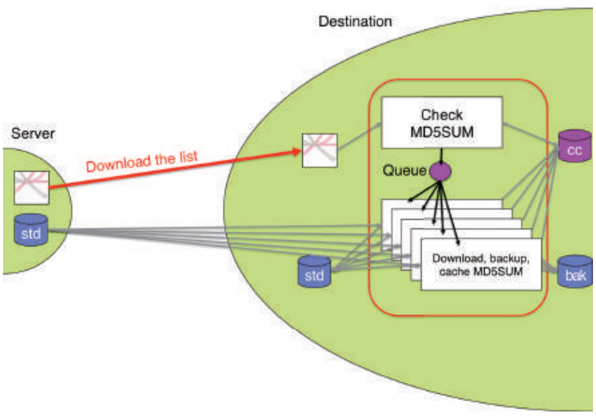

Fig. 4 Caching local MD5 message-digest

was introduced. The modified first step is to compare the cached local MD5 message-digest and MD5 message-digest in mokuroku.csv.gz. The calculation of MD5 message-digest for the local copy is performed only when the first comparison fails. By introducing this, the synchronization process becomes a few times faster.

4.5 Performance

The performance of qdltc depends mainly on the quality of the Internet connection and the performance of the hard disk drive where the tiles are stored.

It takes about a week to download a whole tile-set of the standard topographic maps, and it takes about 3 to 9 hours to reflect weekly updates with a typical consumer-level PC. The performance is known to be significantly better under a server-level environment. The performance of the anti-virus software sometimes has effects on the performance of the software.

5. Future Directions

The idea of differential updates by using the GSI Tile List can be applied for not only downloading but also uploading of the tiles. Use of the idea of the GSI Tile List in the uploading process may lead to more rapid updates of the served data.

The backup data stored by qdltc can be used as an archive of the GSI Tiles. Ways to visualize and access the backup need to be developed. Simultaneously, the specification of the modification time (mtime) of the tile-file needs refinement. Possibly the modification time of the tile-file should be the official publication time of the geospatial information.

By taking these measures, it is preferable to consider tile data as a key currency of geospatial information, working online and offline across web maps, desktop GIS, mobile applications, and tablet applications.

It is worth noting that the proposed synchronization method is independent of the contents of the tile-set. This means the method is applicable for vector tiles or tiles from other sources. The Information Access Division would like to modularize the implementation of the proposed method as much as possible, and contribute to open innovation in the application of geospatial information.

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Implementation of Ishioka VGOS Station

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(Published online: 28 December 2015)

Abstract

The Geospatial Information Authority of Japan (GSI) started a new project to construct a VGOS (VLBI Global Observing System) station in Japan. Construction of the antenna (radio telescope) is complete, and the necessary equipment (Front-end, Back-end, H-maser, and so on) has been delivered. The name of the new site is the Ishioka Geodetic Observing Station. It is located 16.6 km away from the Tsukuba 32-m antenna. We briefly report on the implementation of the new station, especially the initial receiving performance of the new antenna, and the first geodetic results of VLBI observations carried out after February 2015.

1. Introduction

The Geospatial Information Authority of Japan (GSI) has carried out Very Long Baseline Interferometry (VLBI) observations since 1981. In the first period, from 1981 to 1994, we developed transportable VLBI systems with a 5-m antenna and a 2.4-m antenna, and used them to carry out domestic observations. Eight sites in Japan were observed, and their precise positions determined. In addition, joint Japan-Korea VLBI observations were carried out using a transportable 3.8-m antenna in 1995. In these observations, the Kashima 26-m antenna, which was removed in 2002, was used as the main station. Next, in the second period from 1994 to 1998, GSI established four permanent stations: the Tsukuba 32-m, Shintotsukawa 3.8-m, Chichijima 10-m, and Aira 10-m antennas. Regular VLBI observations using the four stations are being done. In particular, the Tsukuba 32-m antenna is a main station not only for domestic but also for international VLBI observations.

In 2011, GSI started a project to construct a new antenna following the VLBI2010 concept (Petrachenko et al., 2009), which is recommended by the International VLBI Service for Geodesy and Astrometry (IVS) as the next-generation VLBI system. ‘VLBI2010’ is now called VGOS (VLBI Global Observing System).

This paper gives an outline of the project, the initial receiving performance of the new antenna, and the first geodetic results of VLBI observations that have been carried out since February 2015.

2. Observing Facilities

In the new project, observing facilities were constructed. The conceptual design, consisting of six components, is depicted in Figure 1. As of October 1, 2015 temporary operation rooms are installed instead of the Operation Building, which will be completed by the end of February 2016.

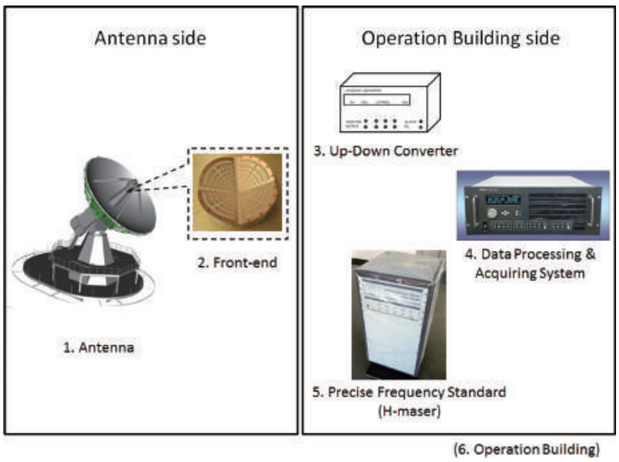

Fig. 1 Conceptual design of the new observing facilities

3. Site Information

The site is located in Ishioka in Ibaraki prefecture, which is near Tsukuba (about 16.6 km-NE from GSI). GSI rents the land from Ibaraki prefecture, and the station is installed in the grounds of the Ibaraki Prefectural Livestock Research Center. The site's name is the Ishioka Geodetic Observing Station (iGOS), because there is not only a VLBI, but also a Global Navigation Satellite System (GNSS) observation point and a Gravity measurement room. The location of the new station is shown in Figure 2. According to the results of a soil investigation of the site, the bedrock lies near to the surface, at a depth of less than 3 meters. This fact suggests that the groundwater effect, which has been the cause of the vertical movements at the Tsukuba station, may be avoidable (Munekane et al., 2010).

Fig. 2 Location of the new station

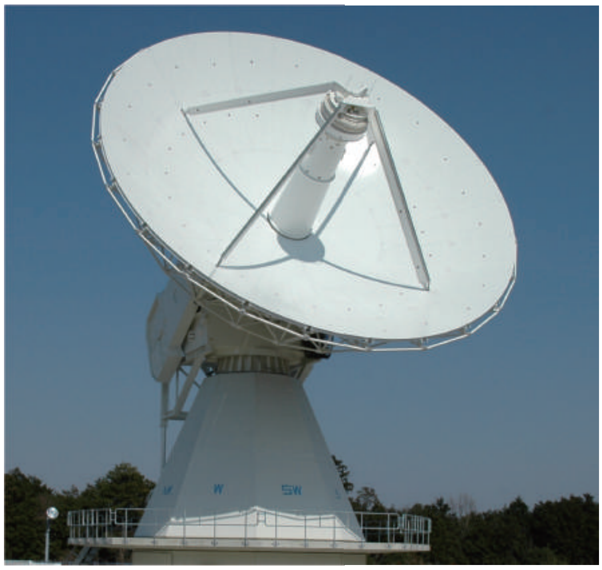

Fig. 3 Photo of the new antenna

Table 1 Specifications of the new antenna

Parameter	Value
Diameter	13.2 m
RF frequency range	2-14 GHz
Optics	Ring Focus
Surface accuracy	≦ 0.1 mm(rms)
AZ maximum slew rate	12°/sec
EL maximum slew rate	6°/sec
AZ maximum acceleration rate	3°/sec^2
EL maximum acceleration rate	3°/sec^2
Special features	Reference point can be measured directly from the ground for co-location.

4. Antenna and Front-end

4.1 Antenna

The antenna (radio telescope) is the main part of the observing system (Figure 3). Since a single antenna is employed, very high slew rates are specified, to comply with the VGOS concept. In addition, Ring Focus optics was applied for the antenna design to match the beam pattern of the broadband feed. The specifications of the antenna are listed in Table 1.

4.2 Front-end

According to the VGOS concept, a broadband feed is necessary to achieve high aperture efficiency over 2-14 GHz. Because the Eleven feed, which has been developed at Chalmers University of Technology in Sweden, and the Quadruple-Ridged Flared Horn (QRFH), which is developed at the California Institute of Technology (Caltech), are both practical as a broadband feed, both feed systems were purchased. Which of these two feeds to employ will be determined after evaluation of the antenna receiving performance with the two feeds.

In both cases, each feed and its Low Noise

Amplifiers (LNAs) is installed in a separate cryogenic system whose physical temperature is less than 20 K. The measured receiver noise temperatures for the QRFH system are less than approximately 30 K for both polarizations (see Fig. 4.).

In addition, to achieve compatibility with the legacy S/X band observation, a tri-band feed system was also purchased. The initial receiving performance was measured using the tri-band feed system (see the following section).

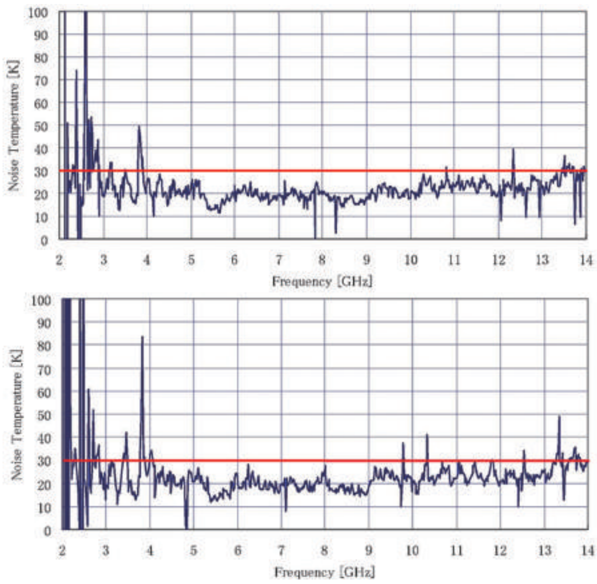

Fig. 4 Receiver noise temperatures for QRFH system (Upper: Horizontal polarization, Lower: Vertical polarization)

Table 2 Specifications of the front-end

Parameter	Value
RF frequency range	2-14 GHz
Polarization	Dual linear polarization
Feed	Eleven feed or QRFH
Dewar	Feed, LNAs, and other devices should be included and cooled by cryogenic system.
Physical temperature	≦ 20 K
Receive noise temperature	≦ 30 K
Total gain	≧ 45 dB
Output frequency range	2-14 GHz
Number of outputs	2 (for dual linear polarization)
Phase and delay calibration	New P-cal unit designed by Haystack Observatory, New cable calibration system developed by NICT
Injection of P-cal/noisesource	Pre-feed (Eleven feed) or pre-LNA (QRFH)

A phase and cable calibration system was also installed. A new type of P-cal unit, designed by the Haystack observatory, has been developed and employed. In addition, instead of the present D-cal unit, a new cable calibration system developed by the National Institute of Information and Communications Technology (NICT) is also employed. The specifications of the front-end are shown in Table 2.

5. Receiving Performance

First of all, the receiving performance of the new antenna with tri-band feed system was tested by measuring radio signals from some strong radio stars (Cas-A, Taurus-A, Virgo-A). The SEFD values for the X and S bands were approximately 1,250 Jy and 1,700 Jy, respectively. This means that the aperture efficiencies for the X and S bands are 77% and 59% respectively, if the system noise temperature is assumed to be 50 K. High receiving performance for the X band was confirmed as a feature of the Ring Focus optics. The receiving performance for the Ka band has not been measured yet.

As a next step, the receiving performance with QRFH system was measured. Unfortunately only the sun was detectable, and it was realized that modification of the cryogenic dewar would be necessary to improve the sensitivity of QRFH. We are planning to improve the cryogenic dewar by the end of March 2016.

Finally, the receiving performance with Eleven feed was measured by receiving radio signals from some strong radio stars (Cas-A, Taurus-A, Cygnus-A). The SEFD values in the frequency range from 3 to 14 GHz are shown in Figure 5. The SEFD values less than 9 GHz are acceptable (less than 2,000 Jy), but unfortunately SEFD values greater than 10 GHz get worse and reach 7,500 Jy at 14 GHz.

On the other hand, radio frequency interference (RFI) is more serious than expected because of a feature of Ring Focus optics. In the case of Ring Focus optics, the aperture efficiency is better, but artificial radio signals can reach the feed more easily than the usually-used optics like Cassegrain. At the new station, the RFI caused by the radio signals for cellular phones is so strong in the frequency range less than 2.1 GHz that saturation of the amplifiers for the S band occurs. In order to avoid the saturation of the S band amplifiers, three types of filters, High Pass Filter (cut less than 2.2 GHz), Notch Filter (cut 2.1 GHz), and Band Pass Filter (pass 2.2-2.4 GHz), are installed in the signal chain of the antenna, and VLBI observation can be carried out normally at present.

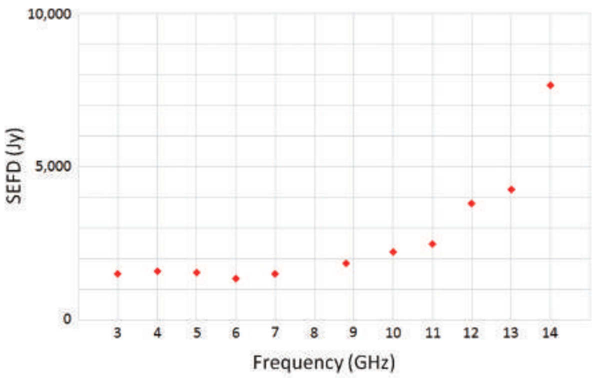

Fig. 5 SEFD values of the new antenna with Eleven feed

6. First Geodetic Result

The first geodetic VLBI observation at Ishioka station was carried out in February 2015 in the Japanese domestic network including GSI's VLBI stations (Tsukuba 32-m, Aira 10-m, and Chichijima 10-m antenna). By the end of June 2015, the Ishioka station had participated in two types of VLBI sessions. One is the Japanese domestic session JADE (JApanese Dynamic Earth observation by VLBI) and the other is AOV (Asia-Oceania VLBI group for Geodesy and Astrometry) session, which started in 2015 for the Asia-Oceania region. In total ten 24-h VLBI sessions were observed at Ishioka station, and the precise geodetic results were successfully obtained for JADE sessions, which were analyzed by GSI. The results of baseline length between Ishioka and the Tsukuba 32-m antenna are listed in Table 3. The standard deviation for each session is the range 1-2 mm, which is reasonable for the Ishioka-Tsukuba baseline.

Table 3 Results of baseline length between Ishioka and Tsukuba

Session	Date	Baseline Length
JD1502	Feb. 19	16,606,288.71 ± 1.58mm
JD1503	Mar. 05	16,606,290.88 ± 1.04mm
JD1504	Mar. 12	16,606,285.38 ± 1.39mm
JD1505	Apr. 23	16,606,291.41 ± 1.31mm
JD1506	May. 14	16,606,293.14 ± 1.50mm
JD1507	Jun. 04	16,606,290.03 ± 1.27mm
JD1508	Jun. 11	16,606,291.17 ± 1.34mm

7. Future plan

Parallel observations with the Tsukuba 32-m station using the legacy S/X band mode will be performed by the end of 2016 in order to determine an accurate tie vector between Ishioka and the Tsukuba 32-m antenna, which is very important information to succeed the accurate coordinates of the Tsukuba 32-m antenna, which have been determined by observations over 20 years.

The Ishioka station will also participate in the VGOS session with VGOS stations in the world. The first VGOS session is scheduled in August 2016.

8. Summary

A new project for constructing a new antenna in Japan has started. The new station will be fully compliant with the VGOS concept. The construction of the antenna was completed by the end of March 2014. The measurement of the receiving performance of the antenna was performed, and high aperture efficiency for the X band was confirmed.

The first geodetic VLBI observation was carried out in February 2015, and ten VLBI observations were performed up to June 2015. Precise geodetic results were successfully obtained.

This station will play an important role as a main station in the Asian region instead of the Tsukuba 32-m station in the near future.

Acknowledgements

VLBI operation software developed by National Aeronautics and Space Administration (NASA) is employed at Ishioka station. Installation and customization of this software was performed by NICT under a joint research agreement between GSI and NICT.

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Outputs from the General Technical Development Project in 2011-2014 Towards the Realization of Multi-GNSS Surveying in Japan

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(Published online: 28 December 2015)

Abstract

The Geospatial Information Authority of Japan conducted a research and development project from 2011 to 2014 on the smart use of multi-GNSS signals for more efficient surveying and precise positioning essential in the management of national lands. The project aims to combine signals from various satellite positioning systems, such as GPS, QZSS, GLONASS, and Galileo, collectively called GNSS, to achieve centimeter-level positional accuracy in a short period of time, especially in urban or mountainous areas where satellite visibility is limited. Four years of effort on the smart use of multi-GNSS signals by the General Technical Development Funds of the Ministry of Land, Infrastructure, Transport and Tourism yielded technical outputs such as

1) Methods to handle between-receiver biases to combine multi-GNSS signals,

2) Open source software for multi-GNSS surveying named GSILIB,

3) A draft manual of multi-GNSS surveying applicable to public surveys in Japan.

This paper overviews the project and focuses on major technical outputs.

1. Introduction

Because of its efficiency and accuracy, since its introduction in the mid 1990s, GPS surveying has become an indispensable tool for many aspects of national land management in Japan, from geodetic, public, cadastral and construction surveys to disaster mitigation through crustal deformation monitoring. Nowadays more than two thirds of public surveys are conducted using GPS, and the nationwide network of GPS operated by the Geospatial Information Authority of Japan (GSI) monitors the crustal deformation of the entire Japanese archipelago's earthquakes and volcanic activities in near real-time (Tsuji et al., 2013).

However, as GPS's role has increased, demands from users to overcome the current limitations of GPS surveying have also increased. The first demand is to overcome the limitations on the use of GPS in urban and mountainous areas. Since GPS surveying requires good visibility of at least 4 satellites at both ends of a baseline, planners of control point surveys in both urban and natural canyons cannot choose efficient GPS surveying as the first choice, and have to prepare additional equipment, such as a total station and a targeting mirror, taking more time and human resources for their surveys.

The second demand to shorten the time required for satellite surveying comes mainly from the disaster mitigation sector. Although a real-time kinematic (RTK) GPS survey can achieve several cm horizontal accuracy in a few minutes, rigorous users depend on a static GPS survey with longer observation time of an hour or more, depending on a baseline length, to yield more accurate solutions. These long observation hours become serious for GSI's emergency analysis of GEONET at the time of large earthquakes and volcanic activities. As widely recognized by the disaster mitigation sector in Japan, crustal deformation information from GEONET plays a key role in understanding the geophysical nature of each earthquake or in predicting the process of volcanic activities. However, due to the relatively long baseline length of GEONET, which covers the whole of Japan with an average distance of 20 km, GSI needs at least 3 hours of GPS observation after earthquakes to achieve better than 1 cm horizontal accuracy on a regional scale of about 100 km. This long observation time delays the provision of coseismic deformation fields to the disaster mitigation sector. At the time of the 2011 Tohoku earthquake (magnitude 9.0), the deformation field was reported to the Earthquake Research Committee of the Government about 5 hours after the main shock. Since the main shock caused up to 1.2 m subsidence along the Pacific coast of the east north area of Japan (Nishimura et al., 2011), such information was critical for assuring people's safety from the tsunami and high waves. Thus a quicker response of GEONET is strongly desired. The same is true for volcanic activities, where crustal deformation is one of the few sources of information for detecting movements of underground magma.

These limitations of GPS surveying are expected to be solved or reduced by the recent rise of a multi-GNSS environment with more Global Navigation Satellite Systems (GNSS) and additional new codes and frequency signals (Langley, 2013). The United States is modernizing GPS by deploying a new generation of satellites: Block IIR-M with L2C code, Block IIF with L5 frequency, and Block III to come with L1C code. Russia maintains the full operational capability of GLONASS with 24 satellites. The European Union and China are in a push to deploy their GNSSs named Galileo and BeiDou. Japan successfully launched the first satellite of the Quasi Zenith Satellite System (QZSS) in September 11, 2010, which has interoperability with GPS.

Figure 1 shows an example of the multi-GNSS environment already realized over Japan. A total of 28

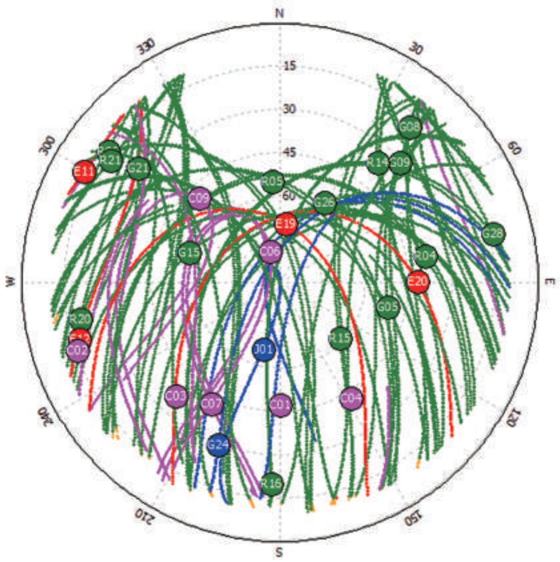

Fig. 1 Sky plot of GNSS data observed by modern GNSS receiver (Trimble NetR9) at Tsukuba from 5:25 to 23:15 UTC on July 17, 2013. G:GPS, E:Galileo, R:GLONASS, J:QZSS, C:BeiDou. The elevation cut off angle is 10 degrees.

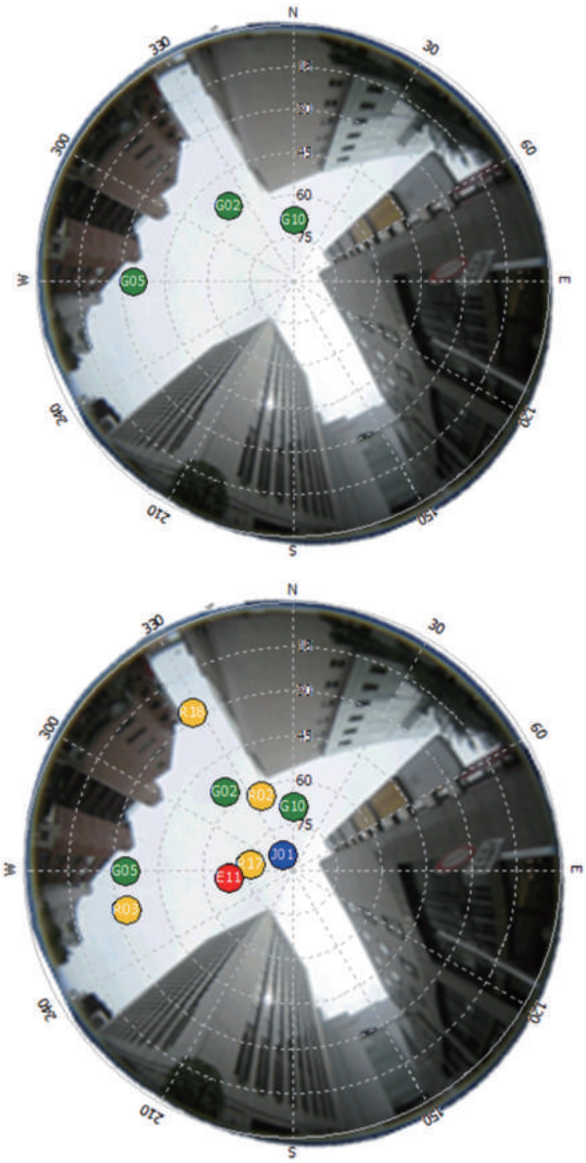

Fig. 2 An example of satellite visibility in an urban canyon of Ginza, Tokyo, at 15:00 UTC November 13, 2013. Above: No hope of positioning with only 3 GPS. Below: Positioning possible with additional 4 GLONASS, 1 QZSS, and 1 Galileo.

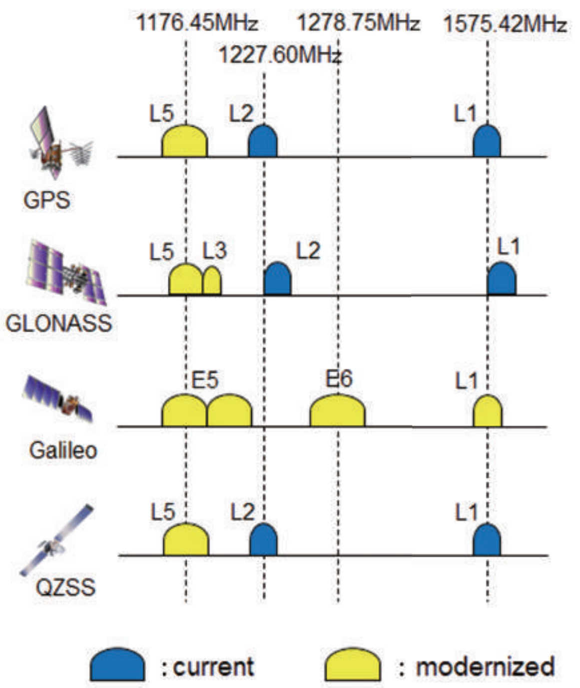

Fig. 3 Frequency bands of GNSS carrier phases in the near future

GNSS satellites were observed at 18:00 July 17, 2013, 8 GPS, 1 QZSS, 8 GLONASS, 4 Galileo, and 7 BeiDou.

It is expected that in the late 2010s, more than 100 multi-GNSS satellites will become available for satellite surveying in Asia and Oceania (Rizos, 2011), improving satellite visibility significantly, and the new L5 (1176.45MHz) signal will assist better and faster solutions when combined with the current L1 (1575.42 MHz) and L2 (1227.60Hz) signals.

Figure 2 illustrates how more GNSS satellites can help to resolve the urban canyon problem of GPS. Additional use of GLONASS, Galileo and QZSS will significantly improve the number of observable satellites.

Figure 3 illustrates the frequency bands of GNSS carrier phases in the near future applicable for surveying.

2. Project

A four year project named “Development of a precise positioning technique using multi-GNSS for advanced management of national lands” was funded as a general technical development project by the Ministry of Land, Infrastructure, Transport and Tourism in 2011, and conducted by GSI with collaborations from various contractors, including universities, under the technical advice of top GNSS experts and related organizations in Japan.

2.1 Objective

The project aims at technical development and standardization of smart use of multi-GNSS such as GPS, QZSS, GLONASS, and Galileo for national land management, to achieve cm level accuracy in a short period of time, especially in urban or mountainous areas where satellite visibility is limited.

The goals are set as follows:

1) Enabling satellite surveying at urban or mountainous areas where GPS surveying fails to work due to poor satellite visibility, by using multi-GNSS satellites, thus reducing costs of satellite surveys,
2) Shortening the observation time of GPS static surveys by using multi-GNSS satellites, thus reducing costs of satellite surveys,
3) Quicker provision of critical crustal deformation information of GEONET after large earthquakes or volcanic activities, and
4) Outreach of Japan’s multi-GNSS techniques including QZSS for Asia and the Pacific region.

2.2 Framework

The project was conducted by the Geodetic Observation Center with close collaboration with the Geography and Crustal Dynamics Research Center and Technical Management Division, Planning Department of GSI. The advisory committee was established by experts from universities, receiver manufacturers, survey companies, providers of network RTK services, and related government organizations in Japan. The committee of 11 members, headed by Prof. Teruyuki Kato of the University of Tokyo, was held 12 times in four years, overseeing the progress of technical developments. All the documents reviewed by the committee are open to the public at the project web site (http://www.gsi.go.jp/eiseisokuchi/gnss_main.html).

2.3 Implementation

The project was divided into three parts and implemented by several contractors.

1) Development of algorithms and software for multi-GNSS data processing. This is the core of the project and most of the resources were spent on software development over 4 years. Reports of algorithms and an open source software package named "GSILIB" with such algorithms are available at the project web site.
2) Field experiments and a simulation study to confirm the techniques developed in the project. Simulation is important as limited availability of actual L5 signals in orbit at an early stage of GNSS. Initial observation and data analysis of QZSS satellite leads to an early incorporation of QZSS into public surveys (Technical Management Division, 2013).
3) Standardization of multi-GNSS surveying for public surveys from 2013 to 2014. The final goal is a revision of the standard operating procedure of public surveys defined by the Minister of Land, Infrastructure, Transport and Tourism, which is the bible for all public surveys in Japan. During the project period, however, we aimed at producing a draft manual of multi-GNSS surveying applicable to some parts of public surveys in accordance with article 17 of the standard operating procedure that allows introduction of new techniques. Using the manuals confirmed by GSI, surveyors can use new techniques in their public surveys without taking time to prove their method is in accordance with the standard operating procedure.

3. Outcomes

Here we introduce major findings and outcomes of the project, which are described in detailed reports at the project web site in Japanese.

3.1 Methods to handle new frequency L5

First we observed L5 signals from GPS Block IIF with modern GNSS receivers, i.e. JAVAD DELTA, Trimble NetR9, Topcon NET-G3, and confirmed that an L5 signal with a high chip rate is less influenced by noise and multipath than an L1 signal (GSI, 2012a). However, in theory L5 alone is more sensitive to ionospheric disturbance than L1 because of its frequency.

Next we investigated algorithms to combine the new L5 signal of modernized GPS with L1 and L2 signals for better ambiguity resolution, which is a key element of GPS data processing, and chose the following two approaches for more studies with simulated L5 signal.

1) Three-Carrier Ambiguity Resolution (TCAR), which uses all L1, L2, and L5 signals to form an extra wide lane linear combination (Teunissen et al., 2002), and
2) Integer Least Squares (ILS) with ionosphere estimation (Takasu and Yasuda, 2010), which is based on the Lambda method (Teunissen, 1995).

RTKLIB: An open source program package for GNSS Positioning (Takasu, 2011) was modified to incorporate ILS analysis with L5 for the studies. A software signal simulator SPSS (Munekane et al., 2008) was also modified to output multi-GNSS signals including L5. By courtesy of JAXA, we collected GPS L5 signal from a hardware signal simulator GSS8000.

Simulation studies with the above GPS L5 data with modified RTKLIB show that

1) ILS with ionosphere estimation approach is better than TCAR from the point of time to fix, fix ratio, and precision for long baselines, but requires a longer analysis time.
2) Usage of 3 frequencies in the ILS method does not bring a dramatic improvement in fix ratio and precision compared to the 2 frequency analysis, but improvement in time to fix is confirmed. Figure 4 is an example of static GPS surveying for a 126 km baseline. The time to fix is reduced to 60 % by the additional use of L5 data in this case.

3.2 Methods to combine multi-GNSS signals

In dealing with signals from different GNSS, we have to consider several biases that originate from the different delays each signal experiences inside receivers, so as to get ambiguity fixed and obtain cm precision (GSI, 2012b; GSI, 2013; GSI, 2014a; GSI, 2015a).

3.2.1 Time and coordinate system

Modern GNSS receivers can track multiple frequency signals from multiple GNSS with

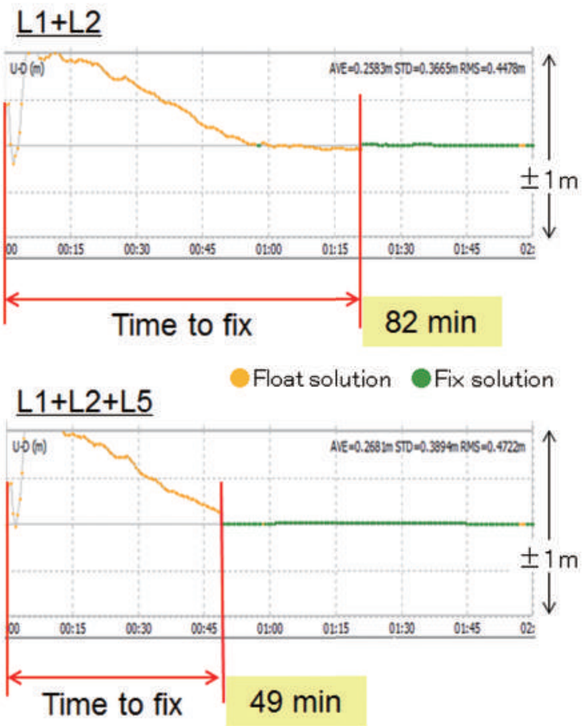

Fig. 4 Reduction of time to fix with L5 data for a static GPS survey of 126km baseline. Two hour observation data with L5 from 8 GPS satellites calculated from the software simulator SPSS and processed with the modified RTKLIB.

interoperability such as GPS, GLONASS, QZSS, Galileo and BeiDou. When we process signals from different GNSS, difference of time and coordinate systems should be corrected first. As is well known, GPS time and GLONASS time have a large discrepancy, as follows.

GPST = GLONAST + leap seconds + C0 + C1,

where C0: UTC - GPST (about 10 ns), C1: UTC - GLONAST (about a few hundred ns). C0 and C1 are available from the Circular T report of BIPM (ftp://ftp2.bipm.org/pub/tai//publication/cirt/cirt.???).

The coordinate systems of GPS (WGS84), Galileo (GTRF), and QZSS (JGS) are almost identical to ITRF, but GLONASS (PZ90.02) again should be corrected to WGS84 by adding -0.36 m in x, 0.08m in y, and 0.18m in the z component. Note that the precision of GLONASS broadcast ephemeris is about three times worse than that of GPS in 2011.

3.2.2 Inter frequency biases for GLONASS

Since present GLONASS distinguishes each satellite by frequency with frequency division multiple access (FDMA), ambiguity resolution of GLONASS needs care. In addition, when different kinds of GNSS receivers are mixed, between-receiver Inter Frequency Bias (IFB) should be corrected (Wanninger, 2011). IFB is also known as inter-channel bias. Estimation of IFB is possible from 12 to 24 hour field observation data at a zero or short baseline with different receivers at both ends by using ANTTOOL (Takasu, 2012). We have estimated the IFB of 4 four kinds of receivers, 6 in total, with respect to a reference one (Figure 5). We also changed

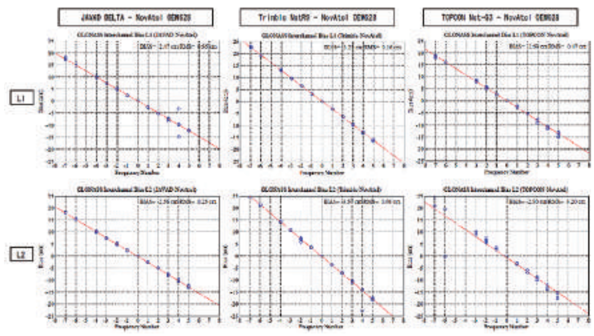

Fig. 5 Estimated IFB of receivers in test (JAVAD DELTA, Trimble NetR9, Topcon NET-G3) with respect to NovAtel OEM628. Note that IFB is well represented by a linear function.

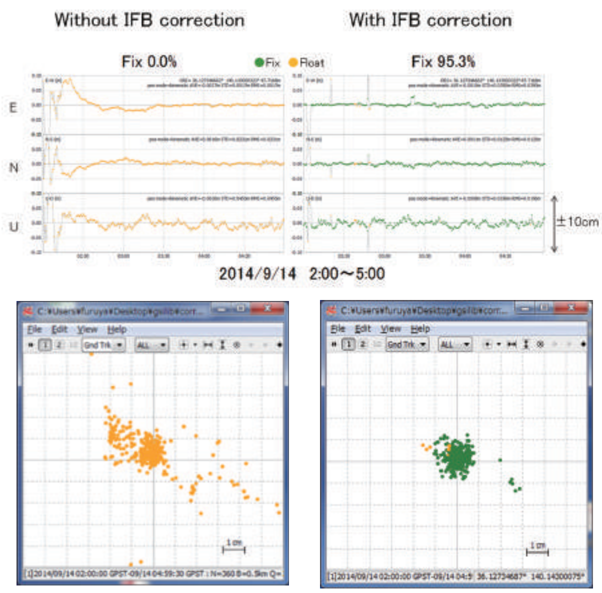

Fig. 6 GPS and GLONASS kinematic solutions of 500 m baseline at Tsukuba on September 14, 2014, between JAVAD DELTA and Leica GR25 receivers. IFB corrections are 53.4mm/MHz for L1 and 68.6mm/MHz for L2 from the zero baseline observation of 12 hours in August 27.

observation conditions such as temperature, antenna, firmware, and reboot of receivers. We found that IFB differs with manufactures but quite stable in time. Thus it is possible to correct IFB with pre-determined values from field observations, enabling GLONASS ambiguity fixing between different receiver types.

Figure 6 shows the effect of GLONASS IFB correction for GPS and GLONASS combination. IFB correction with pre-determined values significantly improves fix ratio and stability of solutions.

3.2.3 Quarter cycle shift in L2C for GPS and QZSS

GPS and QZSS carrier phase generated from new L2C code has a quarter cycle shift from that from existing L2P(Y) code by definition. The problem is that treatment of this shift depends on receiver manufacturers. This could be problematical for GPS and QZSS data processing between different types of receivers. We developed a method to check and correct the sign of quarter cycle shift in L2C. Figure 7 shows the effect of the quarter cycle shift correction for GPS and QZSS combination.

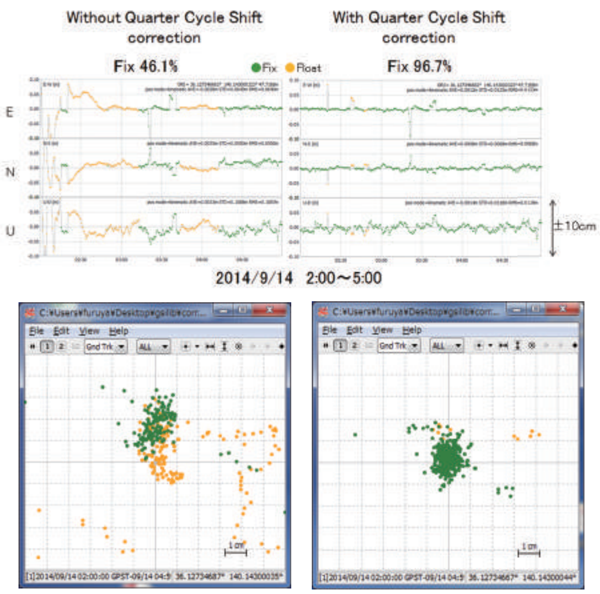

Fig. 7 GPS and QZSS kinematic solutions of 500 m baseline at Tsukuba on September 14, 2014, between JAVAD DELTA and Trimble NetR9 receivers. We previously confirmed that quarter cycle shift corrections for JAVAD as +1/4, and Trimble as 0.

3.2.4 Inter system biases between multi-GNSS

Forming "inter-system" double difference (DD) is a simple but straightforward way to make full use of multi-GNSS for surveying, especially in urban canyons where satellite visibility is limited. For example, if we can make DD observable between GPS and Galileo, we have a good chance to obtain ambiguity fixed solution from 3 GPS and 1 Galileo observations in theory. But to do so, we have to look into another bias named Inter System Bias (ISB) (Odijk and Teunissen, 2013).

Figure 8 illustrates ISB for multi-GNSS along

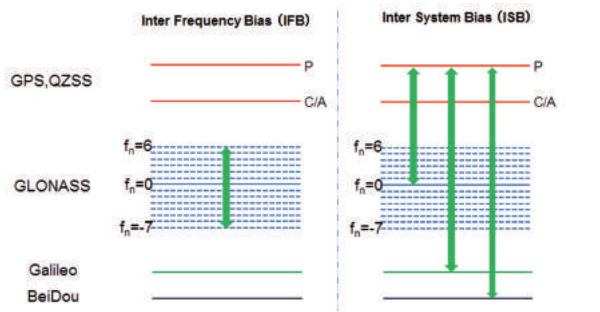

Fig. 8 Schematic view of GLONASS IFB and multi-GNSS ISB. Green arrows show each bias.

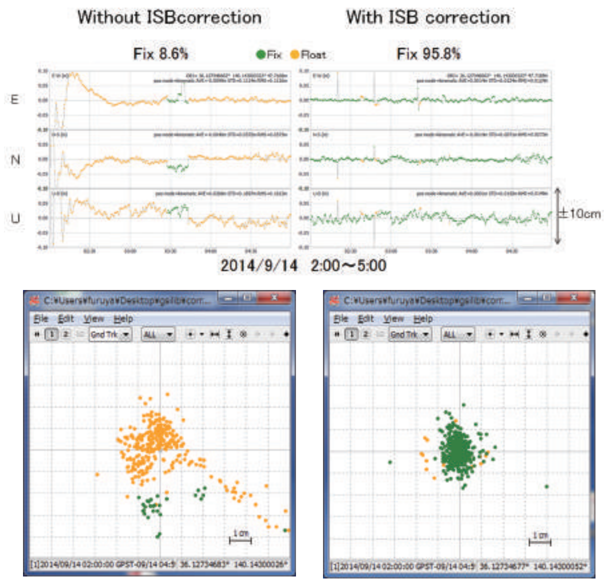

Fig. 9 GPS and Galileo kinematic solutions of 500 m baseline at Tsukuba city on September 14, 2014, between JAVAD DELTA and Trimble NetR9 receivers. Ambiguities between GPS and Galileo are successfully resolved with ISB correction of Code L1 -6.015 ns, Code L5 -20.210 ns, Phase L1 0.141 ns, and Phase L5 -0.002 ns, that are estimated from the zero baseline observation of 24 hours on August 27 and 28.

with the IFB for GLONASS mentioned at section 3.2.2. ISB originates from different delays of each GNSS signal experiences inside receiver hardware, therefore if different receivers are used at both ends of baseline, ISB should be estimated. We developed a method to estimate relative ISB using field observation data of a zero-baseline and examined the nature of ISB for modern GNSS receivers like IFB (Furuya et al., 2015).

As a result, we found that

1) ISB (phase) for GPS - GLONASS is not stable and changes with temperatures and reboot of receivers. So we cannot use pre-determined ISB related to GLONASS. This means inter-system DD with GLONASS is difficult to fix.
2) ISB (phase) for GPS - Galileo and GPS - QZSS is stable, so we can fix inter-system DD using pre-determined values for these combinations.
3) ISB (code) is not stable for most cases but we confirmed it has less effect in positioning.

Figure 9 shows the effect of ISB (phase) correction for GPS and Galileo combination.

3.2.5 Half cycle shift for BeiDou

We add tests of BeiDou after China released an official version of an interface control document on December 27, 2012. BeiDou transmits B1 (1561.098 MHz), B2 (1207.14 MHz), and B3 (1268.52 MHz) signals from GEO (Geostationary Earth Orbit), IGSO (Inclined Geosynchronous Orbit) and MEO (Medium Earth Orbit) satellites. BeiDou has a half cycle shift in carrier phase between GEO, IGSO, and MEO, and the treatment of the shift is dependent on receiver manufacture. Figure 10 shows the effect of half cycle shift correction of BeiDou.

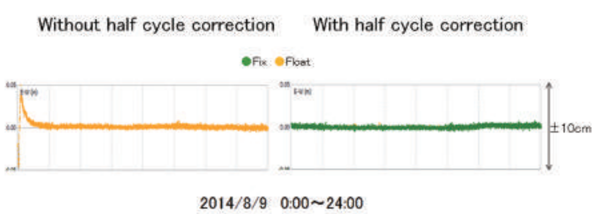

Fig. 10 GPS and BeiDou kinematic solutions of zero baseline at Etchujima, Tokyo on August 9, 2014, between JAVAD DELTA and Trimble NetR9 receivers.

3.3 Open source multi-GNSS analysis software: GSILIB

By summing up improvements to RTKLIB in the project, we have developed a derivative open source software package named GSILIB (GNSS Surveying Implementation LIBrary), which runs on a Windows PC (Furuya et al., 2013). Following the open source license of RTKLIB ver.2.4.2, GSILIB is provided from the project web site under the BSD 2-clause license, which does not require open source code when revised by users. We also provide ANTapp which do the same work as ANTTOOL without Matlab under GPL v3 license.

There have been nearly 1000 downloads of GSILIB and ANTapp since January 2015. To promote multi-GNSS surveying using GSILIB, we had several seminars in Japan, as well as held a tutorial seminar at Phuket at the time of Asia Oceania Regional Workshop on GNSS in 2014.

Fig. 11 Interface and output view of GSILIB. GSILIB is a derivation from RTKLIB specialized in dealing with biases in multi-GNSS surveying.

3.4 Application of PPP for GEONET deformation monitoring

Since quicker provision of crustal deformation fields from GEONET at the time of earthquakes or volcanic activities is of high priority, we investigated the feasibility of using Precise Point Positioning (PPP) and PPP-AR (Ambiguity Resolution) techniques in addition to multi-GNSS option. From the point of CPU time, PPP/ PPP-AR is attractive compared to the time-consuming baseline analysis. However, PPP/ PPP-AR requires precise orbit and clock information, whose sources are currently limited. We have used real-time CNT data from CNES (http://www.ppp-wizard.net/index.html).

Figure 12 shows an example of whole GEONET analysis by baseline analysis and PPP/PPP-AR (GSI, 2014b). The CPU time by PPP/PPP-AR with RTKLIB is only 0.5 minutes to process about 1200 stations, whereas baseline processing with Bernese 5.2 took 12 to 15 minutes using 6 servers with 8 cores each. Note that 1 hour GPS baseline solutions are not so stable, but additional use of GLONASS stabilizes solutions. Currently CNES provide only GPS ephemeris for PPP/ PPP-AR.

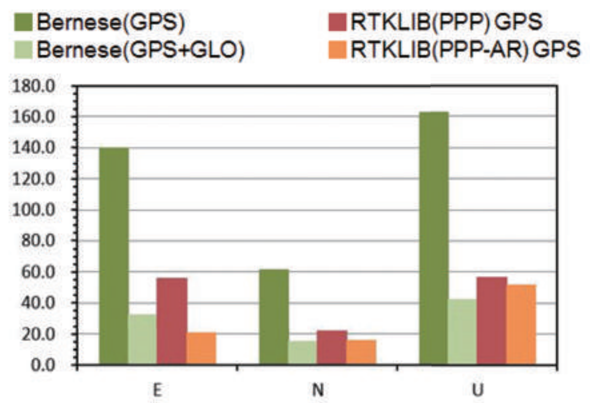

Fig. 12 Standard deviations of 1 hour static solutions of GEONET (median of whole stations) in mm on October 4, 2013 by 1) baseline analysis with GPS only and with GLONASS, and 2) PPP/PPP-AR with GPS. IGS ultra rapid orbit is used for the baseline analysis, and CNES's real-time CNT ephemeris is used for PPP/PPP-AR.

3.5 Draft manual of multi-GNSS surveying for public surveys

Based on several simulation studies and field observations of multi-GNSS with GSILIB processing, we made a draft manual of multi-GNSS surveying applicable to some part of public surveys, under the guidance of another advisory committee headed by Prof. Tatsunori Sada of Nihon University (GSI, 2015b). With this manual, usage of GPS, GLONASS, QZSS, and Galileo becomes possible in public surveys in Japan. A special method to combine inter-system DD of multi-GNSS is described for urban surveys.

4. Future works

Although the initial project ended in March 2015, we continue to work on the following items to promote multi-GNSS surveying in Japan.

1) Field evaluations of L5 data
2) Examination of new Code Division Multiple Access (CDMA) signal from GLONASS-K satellite
3) Improvement of multipath reduction for urban areas
4) Promotion of the draft manual and its revision
5) Maintenance of GSILIB

5. Conclusions

In response to the advent of a multi-GNSS environment, GSI conducted a four year technical development of a smart use of multiple frequency signals from multiple satellite systems for more efficient surveys and quicker crustal deformation monitoring in Japan. Although each GNSS is designed to have basic interoperability with other systems, combining carrier phase signals from different GNSS requires careful calibration of biases, such as the GLONASS IFB, ISB, the quarter cycle shift of L2C, and the BeiDou half cycle shift, in order to make full use of multi-GNSS. We modified the existing open source software RTKLIB to handle these biases and set up a package as GSILIB for precise surveying in multi-GNSS environment. Based on simulation studies and field observation analyses, we also set up a standard procedure of multi-GNSS surveying, forming a draft manual of multi-GNSS surveying for public surveys.

Looking back, everything was simple in the good old GPS days. With the rise of multi-GNSS, there are very many signal delay biases to be solved for their combinations. GSI will continue to assist surveying and disaster mitigation sectors through technical development to make full and smart use of a multi-GNSS environment.

Acknowledgements

We always admire the efforts of Mr. Tomoji Takasu and his colleagues at Tokyo University of Marine Science and Technology in developing and maintaining RTKLIB as open source software. Feedback from the following advisory committee members was essential in the project: Mr. Haruki Ayada and Mr. Akira Shibuya from SPAC, Dr. Ryuichi Ichikawa from NICT, Prof.

Teruyuki Kato from ERI, University of Tokyo, Mr. Seiya Kawaguchi, Mr. Motoyuki Hosoya, Mr. Yoshikatsu Iotake from Promotion Council of Real Time Positioning using GPS-based Control Stations, Dr. Satoshi Kogure from JAXA, Dr. Takeyasu Sakai from ENRI, Mr. Akira Sugimoto and Mr. Yasuhiko Hashimoto from Japan Surveying Instruments Manufacturers' Association, Mr. Kouji Hasegawa and Mr. Hiromichi Komatsuzaki from Association of Precise Survey and Applied Technology, Mr. Kouji Kidera from Japan Association of Surveyors, Mr. Katsuo Eda from Japan Federation of Survey and Planning Associations, Prof. Kosuke Heki from Hokkaido University, Prof. emeritus Akio Yasuda and Prof. Nobuaki Kubo from Tokyo University of Marine Science and Technology, Prof. Tatsunori Sada from Nihon University, Mr. Atsushi Morishita from Engineering Affairs Division, Ministry of Land, Infrastructure, Transport and Tourism. We contracted to the following organizations in this project: Aero Asahi Corporation, Pasco Corporation, Tokyo University of Marine Science and Technology, NEC Corporation, Hitachi Zosen Corporation, Fujitsu, Mitsubishi Space Software Co., LTD., and Ritsumeikan University.

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Generating tile-based datasets from old aerial photo data

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(Published online: 28 December 2015)

Abstract

The GSI has archives of aerial photos taken from the pre-war era to the present which are available to the public. Regarding old photos that were taken up to 1974, individual photos cannot be viewed by superimposing them on maps, so it has been difficult to specify such things as locations of photographed objects.

Therefore, utilizing recent advanced image processing techniques, a method has been examined for joining these photos in a simple and easy manner over a wide area and convert them into tile-based dataset so that they can be superimposed on GSI maps.

Furthermore, using this method, aerial photos that were taken by the US Army after the war (hereafter, "US Army photos") of urban areas (mostly urban cores) designated by the government were converted into tiles. This enabled comparisons to be made with photos taken from 1974 on that were already publicly available on the GSI Maps (<http://maps.gsi.go.jp/>), which are Web-based maps provided by GSI on the Internet, and it was apparently possible to see changes in land use in a time series.

In the future, efforts will be made to convert aerial photos taken during the time of the Japanese Imperial Land Survey into tiles using this method, and expand tile-based datasets of past aerial photographs.

1. Introduction

As of this writing (8 September 2015), the GSI houses roughly 1.34 million aerial photographs taken from the pre-war era up to the present time and makes them available to the public. Many of these photographs have been converted into tiles, especially those taken by the GSI from 1974 to 1990, and from 2007 to date. This has made it easy for anyone to view a wide area seamlessly on the GSI Maps. However, older aerial photos have not been converted into tiles, the only way they could be viewed was by confirming the position and orientation of each individual photo.

At the same time, as photographic processing techniques have come into general use due to the popularization of panorama photography, UAV, etc., image processing and orthographical projection can now be done more easily and over a wider area. Therefore, in FY 2014, old aerial photographs that had not been converted into tiles were geometrically converted using these image processing and orthographical projection techniques so that they could be overlain on maps, and a method was examined for converting this data into tiles to view on the GSI Maps.

Furthermore, using this method US Army photos from 1945 to 1950 were converted into tiles, and in March 2015 the tiled data of urban areas designated by the government at the time were publicly released on the GSI Maps. Figure 1 shows publicly released map areas.

Figure 2 shows photograph taken of the Kasumigaseki area of Tokyo. It is a composite mosaic of a photo that was taken on 29 March 1948 of the governmental offices area of Kasumigaseki (Course No. M871), and a photo of the Imperial Palace in the upper section that was taken on 24 July 1947 (Course No. M859).

Using this method, it was possible to convert many US Army photos into tiles in a wide area. However, because those photos were taken a long time ago, it became apparent that there were numerous issues to be resolved, such as deterioration of film and photographic

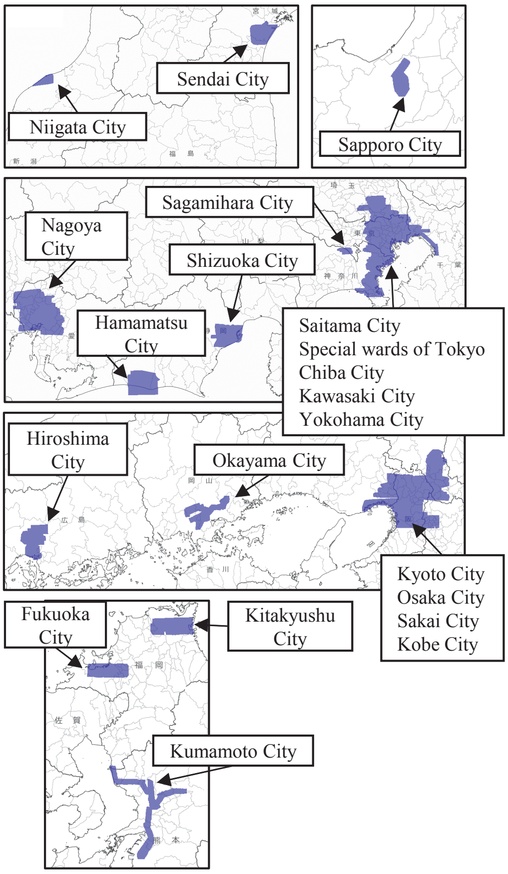

Fig. 1 Publicly released map areas (blue sections)

Fig. 2 Area around Kasumigaseki

procedures which meant that trial-and-error had to be used to convert some of the photos into tiles. The following is a description of the methods that were examined and issues that occurred in this study.

2. Orthographic projection

When doing the geometric conversions so that data of aerial photographic images could be overlain on maps, the work that required the most effort was orientation work for determining corresponding points between pixels of aerial photo image data and map locations. Because this work fundamentally had to be done by hand, it was important to shorten this work to make tile conversion as efficient and effective as possible.

When orienting overlapping aerial photo image data one photo at a time, there was clearly much redundant work involved, and if there was a lot of undulation, it would require numerous reference points to indicate the same point, making it an extremely expensive undertaking.

Therefore, it was decided to reduce distortions caused by undulation and reduce the number of final orientation points by creating ortho-mosaic images of wide areas using bundle block adjustment.

2.1 Bundle block adjustment software

Although there are many types of bundle block adjustment software, it was decided to use the “Pix4d mapper” (hereafter, “pix4d”) made by the Pix4d Company of Switzerland because it was used to create ortho-mosaic images of aerial photographs that were taken of Nishinoshima Island in March 2014 using UAV.

Pix4d is an ortho-mosaic software with powerful image matching functions, which requires only a few settings and steps to create an ortho-image easily from multiple aerial photos. The objective ortho-mosaic image can be obtained in just 3 steps: (1) internal and external orientation, (2) creation of a set of 3-dimensional points, and (3) creation of ortho-mosaic and DSM images.

In order to start-up pix4d and execute the first step (1) of internal and external orientation, it is necessary to have photo data and information about the locations (longitude, latitude, altitude of shooting point), film size, focal distance, and other information. This information is converted into the necessary written CSV format from the records stored by GSI. Once the internal and external orientation is completed, it becomes possible to obtain estimated locations from which each photo was taken and rotation (κ, φ, ω), which can be confirmed visually on the GUI (Fig. 3).

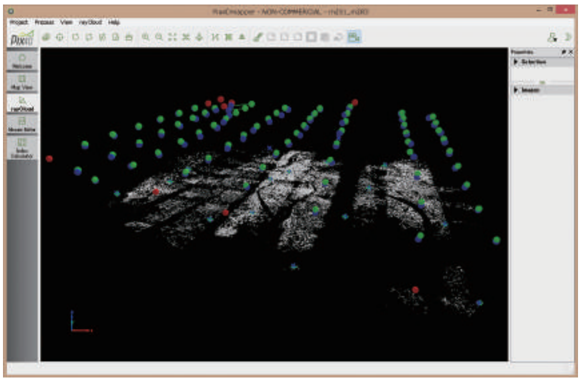

Fig. 3 Display of results of internal and external orientation

The green points are the locations of the initial shooting points of each photograph, the blue points are the locations of estimated shooting points, and the red points are shooting points of photos that could not be used.

If there are no problems with these results, then we can proceed to step (2), creating a set of 3-dimensional points. This creates a 3D model that is necessary for orthographic projection (Fig. 4).

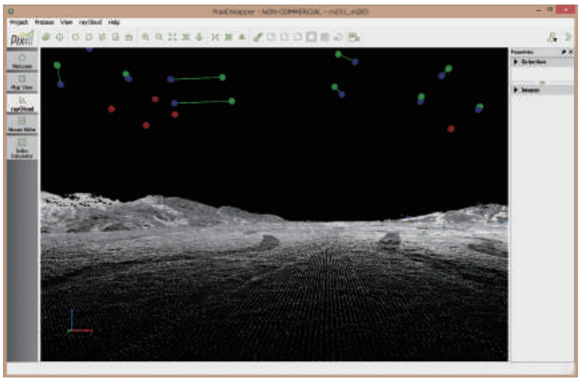

Fig. 4 Display of a 3D model

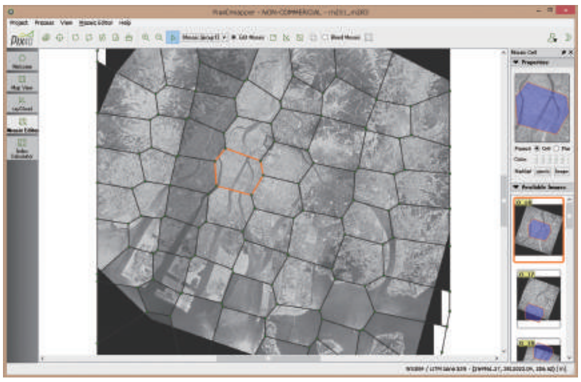

Fig. 5 Display of ortho-mosaic images

If there are no problems with the 3D model, then we proceed to step (3), creation of ortho-mosaic and DSM images. This step will enable us to obtain an ortho-mosaic image (Fig. 5).

2.2 Issues with orthographic projection

2.2.1 Automatic acquisition of tie points and pass points

Pix4d uses image matching techniques to enable automatic acquisition of tie points and pass points required for bundle block adjustment. However, sometimes cannot be done due to such factors as clouds, poor image quality, etc., and areas appear where orthographic projection cannot be done (Figs. 6, 7).

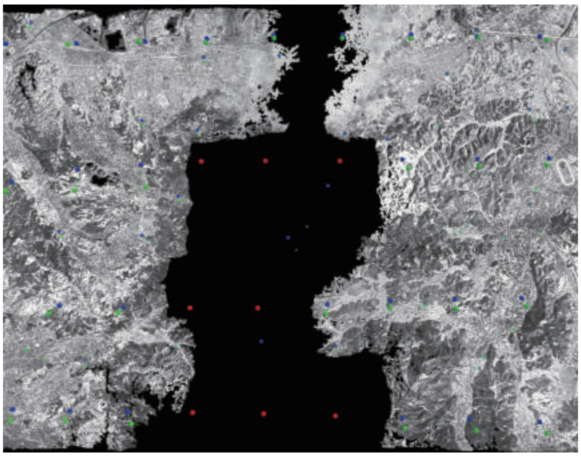

Fig. 6 Example of an area where orthographic projection cannot be done

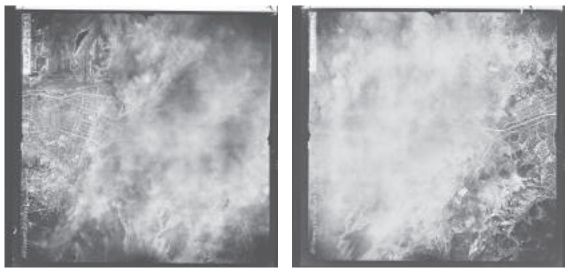

Fig. 7 Examples of photos showing clouds that caused images to be unmatched or mismatched

There are a few cases where image matching is done by adding tie points manually.

2.2.2 Effect of flying conditions on aerial photographs

The US Army photos were not always taken under stable flying conditions and at a fixed altitude, and photos could not always be taken perpendicular to the land surface. In addition, initial parameters that are entered into bundle block adjustment are based on such things as approximate shooting locations which were estimated from maps and flight plan information, rather than actual shooting positions, so there are many cases where calculations have been unsuccessful under such conditions. Figure 8 shows an unsuccessful result where photos could not be melded together. We can probably conclude that the photos were not taken perpendicular to the ground surface.

In cases where there is a single pass point on the photographic course, there is no overlap between pass points, and we can see that the results of bundle block adjustment are not consistent.

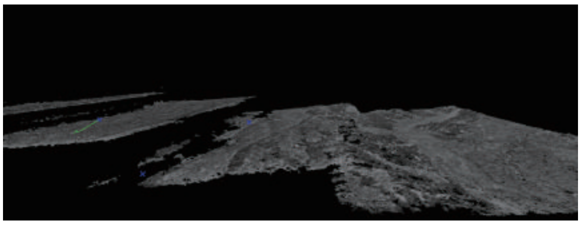

Fig. 8 Example of an unsuccessful result

2.2.3 Artifacts

When the condition of a photo is bad due to, for example, writing on the image, and pixels that have no

Fig. 9 Examples of artifacts

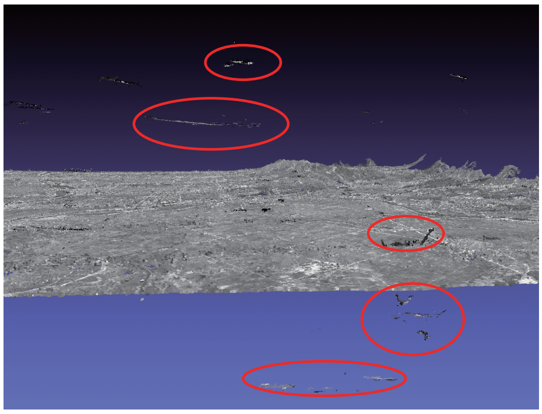

Fig. 10 Example of point sets that caused artifacts

relation to one another are matched up, then the image in that section may have become extremely distorted. This type of section is called an “artifact” (Fig. 9).

Such mistakes in pixel matching are expressed as point sets in unnatural locations in the 3D point set data (Fig. 10).

Therefore, 3D data editing software was used to remove problematic point sets and once again conduct mosaic conversion processing to control the generation of artifacts.

3. Panorama method

When orthographic projection cannot be done due to various factors, then panorama processing was done in which overlapping sections of multiple photographs were joined by automatic image matching, and then attempts were made to create wide area mosaic images. Panorama processing technology has become common due to widespread use in digital cameras, smartphones, and other devices, and there are many types of software in existence. In this work, we used “Image Composite Editor” which is a free software provided by Microsoft Corporation. Using this software, reference points

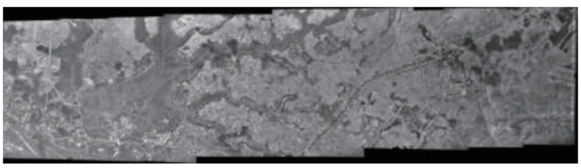

Fig. 11 Example of panorama processing of 8 photographs (vicinity of Funabashi City)

were set for each individual photographic image which eliminated the need to do geometric conversion and could thus save our work. However, flat land areas were selected for this process to avoid local deviations of photo images due to undulation. Then reference points were set in the geometric conversion of the post-processing and combined with absolute positions (Fig. 11).

4. US Army photos that were used in this study

This study used 400dpi resolution JPEG images rather than the 1200dpi TIFF images of our surveying results. This was because 400dpi was a resolution at which several hundred photo images could be compiled and orthographically projected within a few hours. In the case of 1200dpi images, it would take more than one day to process 10 images, even for just orthogonal processing. Furthermore, the size of mosaic images created therefrom would have encompassed hundreds of thousands of pixels, and it would have been difficult to do the post-processing such as geometric conversions, tile conversions, and so on with our workstations, software, etc.

The scale of the US Army photos that were used here basically ranged from ca. 1/10,000 to 1/15,000, and after the processing of the 400dpi photo images, the resolution was about 70-100 cm per pixel. The maximum resolution that can be displayed on GSI maps (zoom level 18) is about 50 cm per pixel, at around a latitude of 35°. Therefore, the tile images that were created here from US Army photos can be said to correspond to a zoom level of 17.

If 1200dpi photo images had been used, then it would have certainly been possible to confirm distinctive planimetric features (Fig. 12). However, because consideration was also given to using GSI maps to look down on a wide area to understand the shapes and positions of planimetric features, and making more detailed checks with crude photographs, it was decided to use, given the current state of productivity, 400dpi JPEG images.

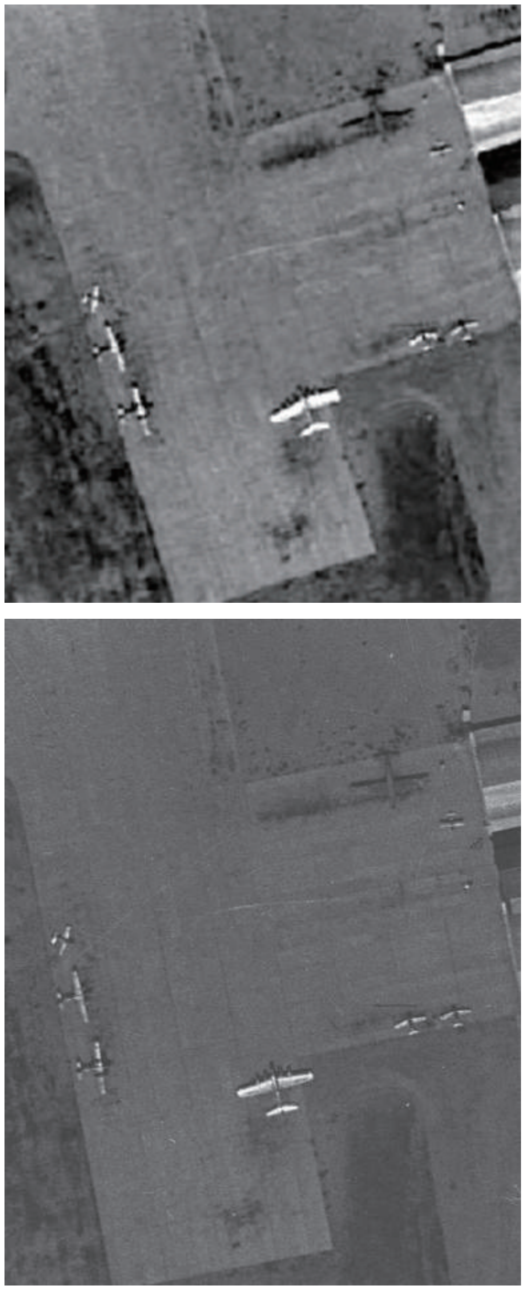

Fig. 12 Differences: 400 dpi (top), and 1200dpi (bottom)

Although the 1200dpi image is more distinctive, in both images the engines of aircraft on a tarmac can be confirmed.

The years of the photos that were used in this study were from 1945 to 1950, and in cases where there were images of the same location for multiple years, the oldest photo was usually selected.

Although the US Army continued to take photographs after 1950, the GSI began to take aerial photographs of the entire country in the 1960s. Therefore, in order to increase the value as an archive for comparing changes in land use, as a rule photos taken in 1951 or later were not used so that there would be no closeness in years.

5. Geometric conversion

Orthographic projection eliminated local deviations due to undulation, and mosaic images could be obtained with relatively good precision, but there were many cases of divergence from the absolute position. Therefore, GIS software was used to geometrically convert images so that roads, etc., on current GSI maps would match up with reference locations.

In many cases, if 20 or so reference points were set, then geometric conversion by bicubic interpolation (which requires at least 10 reference points) could match map positions with satisfactory accuracy.

However, in cases where there was more deviation in mosaic images due to photographic conditions, or mosaic images were created by panorama conversion, more reference points were set, and geometric conversion was rectified by spline interpolation. When spline interpolation was done, there was fundamentally no error in the reference points, but there were many cases where there was great distortion generated by areas surrounding reference points (extrapolated areas). Therefore, such outer areas were removed from the post-processing.

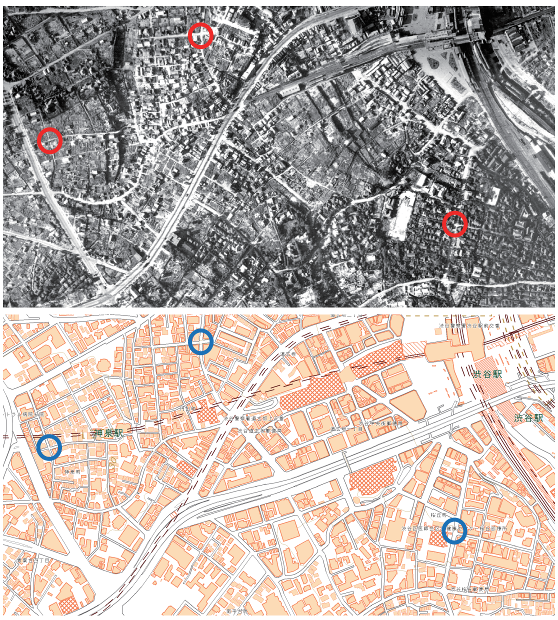

Fig. 13 Example of setting reference points (circles represent corresponding reference points)
(Vicinity of Dogenzaka, near Shibuya Station)
US Army photo (top)
GSI map (bottom)

5.1 Selection of reference points

Over the years, many changes have occurred between the recent GSI maps and the US Army photos, and it is difficult to find planimetric features that are common to both. Basically, road intersections are often used as reference points, but large error can occur if corresponding points cannot be accurately determined due to subsequent road widening, etc. Therefore, it was decided to set reference points in places where there had been no major changes in the old roads (Fig. 13).

Fig. 14 Mouth of old Edo River and vicinity
US Army mosaic image (top)
1:25,000 scale topographic map, surveyed in 1945 (center)
GSI map (standard map) (bottom)

However, for cases where large-scale suburbs had formed, it was not possible to obtain reference points over a wide area. For example, large-scale land reclamation had been undertaken near the mouth of the Edo River, so recent maps could not be used. Therefore, old maps were used to estimate reference points so that there would be no significant deviations (Fig. 14).

6. Removal of edges

Major planimetric features were avoided so that adjacent mosaic images would appear to be merged more cleanly, and image editing software was used to remove edges manually. Basically, in order to avoid a sense of incongruity, the boundaries that were selected for removed edges were such features as ridges in fields and paddies, rivers, forested areas, and areas along roadways.

The removed sections were subjected to transparency processing, then during tile merging of the post-processing, efforts were made not to overlay mosaic images of adjacent photographed areas (Fig. 15).

Fig. 15 Hiyoshi Station area of Yokohama
Image after cropping edges (left)
Merged image (right)

7. Tile conversion

For tile conversion, we used an open source GIS processing library called GDAL. First, the mosaic images were converted into the Web Mercator projection system (EPSG:3857). Then, 256×256 pixel PNG format tile images were created. PNG rather than JPEG images were used in order to save non-photographed areas as transparent areas. After that, we used our own program to merge tiles at the same position with each other to complete the tile conversion of US Army images (Fig. 16).

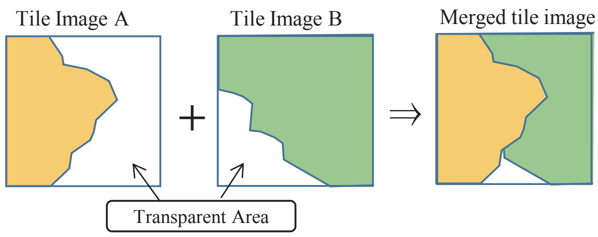

Fig. 16 Merging of tile images

8. Topic for future examination

In this study, 400dpi JPEG data was used to convert areas around government-designated cities (mainly city centers) into tiles in about 9 months. In the future, we will investigate methods for efficiently processing higher resolution data of 1200dpi and above.

However, even with the current computer specs, it is still difficult to do such processing work as orthographic projection unmodified image data of 1200dpi and above, geometric conversion, and so on. Therefore, if we divert the parameters required for orthographic projection obtained at 400dpi and geometric parameters (displacement of each pixel) and apply them to 1200dpi or greater data, then we may be able to reduce the amount of labor needed for orthographic projection and geometric conversion. However, because no such processing programs are available at the current time, we will have to consider creating our own program.

9. Concluding remarks

By creating wide area mosaics using powerful photographic image processing software such as pix4d and panorama conversion software, we were able to efficiently overlay positions on maps. We were also able to easily make tile conversions using open source tools such as GDAL, and there was almost no need to create our own processing programs. Furthermore, we were able to use recent high-spec workstations to process data of image sizes exceeding tens of thousands of pixels with these powerful tools.

However, it became clear that there are still numerous issues to be resolved. For example, due to problems peculiar to US Army photographs such as poor image quality and unstable photographic conditions, mosaic images could not be obtained, and we sometimes had to start over by changing conditions for recalculation, and there were many instances where we could not even use panorama conversion and had to rectify photographs one at a time by hand for tile conversion.

In future studies, we will investigate ways of resolving these issues and efficiently processing 1200dpi images. We also plan to use methods examined in this study to make tile conversions of aerial photos taken by the Japanese Imperial Land Survey in order to improve tile data of old aerial photographs.

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Investigation of Mountain Trails with Regional Partnerships

Akira SASAGAWA, Nobuyuki WATANABE, Kentaro TERASHIMA and Yoshiyuki MIZUTA

(Published online: 28 December 2015)

Abstract

Mountain trails, defined as one of the acquired feature items of the Digital Japan Basic Map, have been investigated locally where changes were pointed out by users such as climbers, because of the difficulty of extracting changes from aerial photographs. Since fiscal 2012, the Geospatial Information Authority of Japan (GSI) has started a new approach to investigate them with regional partnerships such as relevant local agencies and volunteers. This approach enables us to reflect the latest mountain trails on a wide area of the target mountains on the Digital Japan Basic Map. We report the details of the flow of investigations and the methods of surveying mountain trails with regional partnerships, as well as achievements in 2012 and 2013.

1. Introduction

GSI develops and updates the Digital Japan Basic Map, which shows the current status of geospatial features such as detailed terrain in conformance with unified standards. GSI Maps, GSI's webmap service, and the digital topographic map derived from the Digital Japan Basic Map are used not only for administrative purposes such as land management and disaster prevention, but also for climbing, hiking and other purposes.

Though the Digital Japan Basic Map is normally developed and updated using a photogrammetric method, it is difficult to read mountain trails from aerial photographs and update them on the map in many cases, because many parts of the trails are covered by trees, and they are narrow. Therefore, it has been difficult to extract the location to be updated and promptly update the map. In practice, the mountain trails to be updated are determined on the basis of information about the position and shape of the trails obtained from climbers and local governments. Though this makes it possible to update locally, it is difficult to investigate wider areas of mountains collectivity containing a trail network.

In order to solve these problems, GSI has started to investigate mountain trails with regional partnerships such as local government and mountain officials since 2012. This approach enables us to survey and update the trails of the entire area of the target mountain. The details of the approach will be described in the following chapters.

2. Overview of investigation with regional partnership

The mountains whose trails have been investigated with regional partnerships in 2012 and 2013 are shown in Table 1. The trail investigation project with regional

Table 1 The list of mountain subject for investigation

Mountain (Prefectures)	Period (year)	Partner organizations
Mt. Daisen (Tottori Prefecture)	2012 ～	Daisen town, Chugoku Regional Development Bureau, Tottori Prefecture, Tottori Mountaineering Association, Tottori University
Mt. Minamidake (Gifu Prefecture)	2013	The Japanese Alpine Club
Mt. Aso (Kumamoto Prefecture)	2013 ～	Aso city, Aso nature environment office, Aso area Promotion Bureau, Kumamoto Mountain Climbers Association, Takamori town, Minami-Aso village
Mt. Yaotome (Toyama Prefecture)	2013	Toyama Mountain Climbers Association, Doshumichi-No-Kai, Nanto city
Mt. Horaiji (Aichi Prefecture)	2013	Shinshiro city
Mt. Hakone (Kanagawa Prefecture)	2013 ～	Kanagawa high school athletic federation, Hakone town

partnerships named “The trail map made and brought up by people on Mt. Daisen” was firstly established in October 2012, and continued up to 2014. Likewise, trail investigations were also conducted in Mt. Minamidake, Mt. Aso, Mt. Yaotome, Mt. Horaiji and Mt. Hakone areas in 2013, and investigation in Mt. Aso and Mt. Hakone areas were continued up to 2014. Although the partner organizations were different in each area, common investigative methods such as review meetings, field surveys and updating the Digital Japan Basic Map were employed. The details of the methods are shown in the next chapter.

3. Review meetings with partner organizations

For better understanding of the investigation among partner organizations, review meetings were held and the following agenda items were discussed.

1) Current situation of mountain trails that are displayed on the map
2) Mountain trails that should be reflected on the map
3) Selection of the survey point and description of survey method to the members
4) Adjustment of the survey schedule
5) Members who participate in the survey

Each detail is shown as follows.

(1) Current situation of mountain trails route displayed on the map

The current situation of the mountain trails that was displayed on the Digital Japan Basic Map were checked on the basis of the information obtained from the members who know the current situation of the trails.

(2) Mountain trails that should be reflected on the map

The members of the meeting discussed whether a mountain trail should be displayed or removed from the map from the point of view of safety and security for the climbers. The trails that used for distress rescue should be displayed on map. Criteria for removal were as follows.

1) Trails that cannot be used
2) Dangerous trails that contain high risk points such as rockfalls

(3) Selection of the survey point and description of the field survey methods to the members

The survey points were determined on the basis of the result of (2), where the shape data of trails to be added to the map should be acquired by GPS logger and the current situation of trails to be removed on the map should be checked. In the case of Mt. Daisen, trails currently prohibited for use were selected as the target of the field survey, if it is possible that the trails will be available in the future. GSI showed its field survey method to the members of the meeting.

(4) Adjustment of the survey schedule

It is difficult to conduct a field survey of mountain trails in the winter, because of snowfall. Therefore, field surveys should be done before the winter. In the meeting, survey schedule was adjusted for rapid implementation.

(5) The members to participate in survey

The members such as general volunteers recruited by review meeting secretariat went to a field survey, instead of GSI staff. There were some cases that the members of review meeting as well as local government officials joined a field survey without recruited volunteers.

4. An example of urgent survey of mountain trails investigation

GSI had received information that old trails which were not being used were displayed on the map, and that new trails which were being used were not displayed on the map from map users on Mt. Minamidake. These trails were used for senior or intermediate climbers, and contained points with a high risk of getting into distress or slipping down. It was necessary to investigate urgently. The Japanese Alpine Club, with which GSI had signed an agreement, had conducted a survey quickly without holding a review meeting with local agencies.

5. Field survey

GSI rented hand-held GPS loggers (MobileMapper6 and MobileMapper10) and provided a simple operation manual to partner organizations so that investigators including non-expert volunteers could operate them easily. GSI staff taught the operation of the GPS logger to investigators at the first time of the field survey, and GSI staff accompanied investigators to field survey in some cases. The process of a field survey is as follows.

1) Acquiring coordinate and trajectory data of the trails by using GPS logger
2) Taking photographs at the intersection of trails

The specific and detailed method of field survey are as follows.

One survey route was basically surveyed by at least two investigators for accident prevention. When a route was surveyed by one investigator, he/she surveyed the trail route back and forth or acquired data using at least two GPS loggers at the same time. Because the GPS logger was small and could be tied to the backpack, the burden on the investigator was reduced and safety could be ensured.

When they started the field survey, it was necessary to initialize the GPS logger before starting logging data. It requires adjusting the time of the clock in the digital camera. The GPS logger has the ability to acquire data at 2-second intervals on standard settings, and acquire data continuously at 10,000 points (in real time of 5 and a half hours). The GPS logger used for the field survey acquired data continuously even in the shadow of the trees, and the data was good enough quality to get the shape of the trail trajectory. Investigators took photographs to record the situation as shown in Fig.1 at the start point and the end point of trails, if these were newly opened, changed in geometry or could not be used by climbers. The photographs were taken in all directions at the start point and end point of trails, in addition to writing down which directions were to be taken.

Under poor GPS receiving conditions where radio

Fig. 1 An example of the photographs taken at the start point.

waves were blocked by trees, the investigator wrote down the current position on the topographic map as shown in Fig 2, guessing from the surrounding terrain. The notes on the topographic maps were used as support documents for updating the Digital Japan Basic Map where GPS data did not have enough quality to get the shape of the trail trajectory.

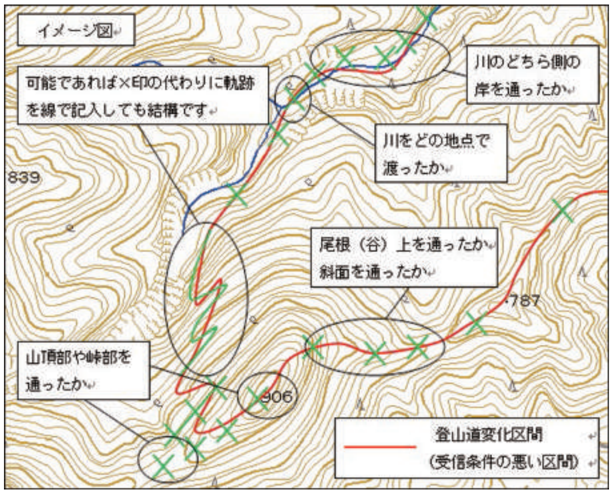

Fig. 2 The example of map noted current position by hand

6. Updating Digital Japan Basic Map

GSI updated the Digital Japan Basic Map data using GPS data acquired in the field survey, to add a new route, to modify geometry, and to delete a route. The data that GSI analyzed based on photographs taken with a digital camera was used to update the map. The mountain trails updated on the map have been made public through GSI Maps. The results of the investigation were published on the GSI website (http://www.gsi.go.jp/kihonjohochousa/kihonjohochous a40023.html) (In Japanese)

The result of investigation on Mt. Daisen is shown in Fig. 3, which shows the target route to the survey, the route to be reflected on the map, the route to be deleted, the routes which were decided not to be displayed on the map in the review meeting, etc.

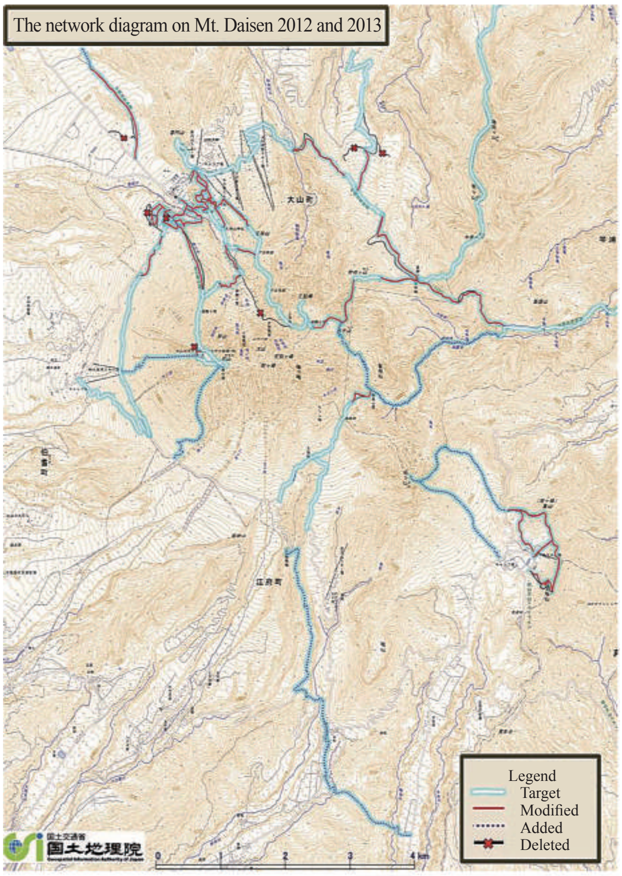

Fig. 3 The network diagram on Mt.Daisen

7. Conclusions

The authors report the details of mountain trailsinvestigation with regional partnership. The model case of mountain trails investigation with regional partnership started in the Mt. Daisen area in 2012. Its efforts have expanded to Mt. Aso, Mt. Yaotome, Mt. Horaiji and Mt. Hakone in 2013. In addition, a survey on Mt. Minamidake was urgently conducted with the cooperation of the Japanese Alpine Club, with which GSI has signed an agreement. Although the scale of each target area for investigations may be different, a framework to investigate mountain trails in cooperation with relevant local agencies and volunteers is being established. The results of the investigations are used for updating the maps and tourist guide maps made by relevant local agencies. It is further expected that it will be widely utilized by relevant local agencies and climbers as the latest and most appropriate information about mountain trails. The authors hope that the investigation of mountain trails with the cooperation of relevant local agencies will be continued, assuming the reflection of latest information of mountain trails on the Digital Japan Basic Map.

平成27年12月28日　印刷
平成27年12月28日　発行

編集兼
発行者　国土交通省国土地理院

〒305-0811　茨城県つくば市北郷１番

国土地理院報告

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