Study on modernizing the General Standard of Operation Specifications for Public Surveys

MURAKAMI Masaki, Japan

Key words: Standardization, modernization, GNSS/CORS, digital camera, public survey

SUMMARY

The General Standard of Operation Specifications for Public Surveys (hereinafter GSOS) is provided by the Geospatial Information Authority of Japan (GSI), the national geospatial organization, served as a model for public organizations to conduct surveying and mapping. GSOS has been updated/developed continually by GSI to include new geospatial concepts and technologies and it works well today.

The basis of GSOS consists of outdated technologies such as control surveys using theodolites/EDMs at triangulation points and photogrammetry using film cameras to make paper maps. Although GSOS already embraced newer technologies such as CORS and digital cameras, they are prescribed on the outdated basis.

The basis of GSOS should be modernized to make full use of capability of modern technologies. We, as a private sector, set up a study group to develop new specifications, contributing to modernizing GSOS. We confine ourselves in putting basis on modern technologies used dominantly today: for control surveys, exclusively use of GNSS, CORS and total stations; for aerial surveys, exclusively use of digital cameras and digital geospatial data.

While retaining GSOS which works well today, we will modernize it for the future needs for accuracy.

Study on modernizing the General Standard of Operation Specifications for Public Surveys

MURAKAMI Masaki, Japan

1. Introduction

Public survey is defined by Survey Act and it means surveys executed either by the national or local governments (GSI, 2015). Survey Act (originally, 1949) has been enforced to ensure efficiency and accuracy in surveys by setting rules and avoiding redundancy. The Geospatial Information Authority of Japan (GSI), as the competent authority of the Survey Act, lays out the basic rules of surveys and seeks to improve the national survey system (GSI, n.d.).

The General Standard of Operation Specifications for Public Surveys (hereinafter GSOS; GSI, 2021) is provided by GSI served as a model for public organizations to conduct surveying and mapping. The use of GSOS is not obligatory but most of public organizations employ it as is, so it can be regarded as the standard for public surveys in Japan.

Though the first version of GSOS was published in 1951, it had not been revised until 2008. Until then, the Operation Specifications for Public Surveys of the Ministry of Construction, published in 1969, had been used as a substitute for GSOS and is regarded as GSOS in this paper. GSOS has been updated/developed continually by GSI to include new geospatial concepts and technologies and it works well today.

In recent years, public surveys (control surveys and photogrammetric surveys) based on CORS with the use of modern equipment and technologies has become mainstream, and it is expected that the positional accuracy of these results can be greatly improved. In this paper, we confine ourselves to the current mainstream methods, clarify the achievable accuracy, and introduce efforts to modernize these standards.

2. Structure and contents of the current GSOS

The current GSOS consists of five parts: 1. General rules, 2. Control surveys, 3. Topographic and photogrammetric surveys, 4. Three-dimensional point cloud surveys, 5. Engineering surveys. The contents of each part are as follows:

Part1 “General rules” describes the objective and scope of the standard, explains legal procedure and need for inspection by third (uninterested) party, and defines the procedure in case of the application of instruments and methods of modern technologies that are not specified in this standard.

Part2 “Control surveys” describes the criteria of the surveys and the operation of preparation, observation, calculation, and quality control/evaluation. This part includes both for horizontal and vertical (leveling) surveys.

Part3 “Topographic and photogrammetric surveys” describes the criteria of the surveys and the operation of preparation, observation on land, aerial photographing, calculation, compilation of map/photo data and quality control/evaluation.

Part4 “Three-dimensional surveys” includes surveys by terrestrial laser scanner and UAV photogrammetry to obtain point cloud data. Surveys by airborne lidar, UAV lidar, mobile mapping system are currently described in Part3, which are planned to be moved to this part in 2023.

Part5 “Engineering surveys” includes river maintenance surveys, road construction surveys, and lot surveys for the acquisition of construction sites.

Though GSOS has been updated/developed continually, no substantial change in quality criteria/control has appeared since 1977. Modern technologies have been adopted and merged by patchworks into old ones in GSOS when updated. We focus on the issues in control surveys and photogrammetric surveys, in which modern equipment and technologies based on CORS are exclusively employed in recent years and new quality criteria and control are required.

2.1 Control Surveys

Leveling surveys are not considered at the moment because GSI plans to release a new gravimetric geoid model (not hybrid model) and considers the introduction of a new height system with the geoid model being its vertical datum in a year or so. We delayed to study issues on leveling surveys with the prospect that the way of leveling will possibly be changed and decided to focus on issues of horizontal control surveys.

2.1.1 Hierarchical structure of control points

GSOS defines the hierarchy of four tiers of control points according to the distance between neighboring points: 1000m for the first tier; 500m for the second tier; 200m for the third tier; 50m for the fourth tier. Instrument performance and survey methods needed for each tier are defined. The association of instruments and methods with four-tier control points is also defined though it has been developed by patchworks, which makes the association complicated (Figure 1).

2.1.2 Quality criteria

Target accuracy of coordinates of control points are 10cm and the accuracy of angle measurements and distance measurements for theodolite/EDM or total station (TS) are specified for each tier. The accuracy of baseline vectors for GNSS observations is also specified.

2.1.3 Survey method

Traversing both for theodolite/EDM or TS and GNSS is employed for the survey. Closed line/network traverse is allowed but not open and close loop traverse. Control points of higher tier are followed by those of consecutive lower in principle though skipping of tier is allowed in a certain condition (Figure 1).

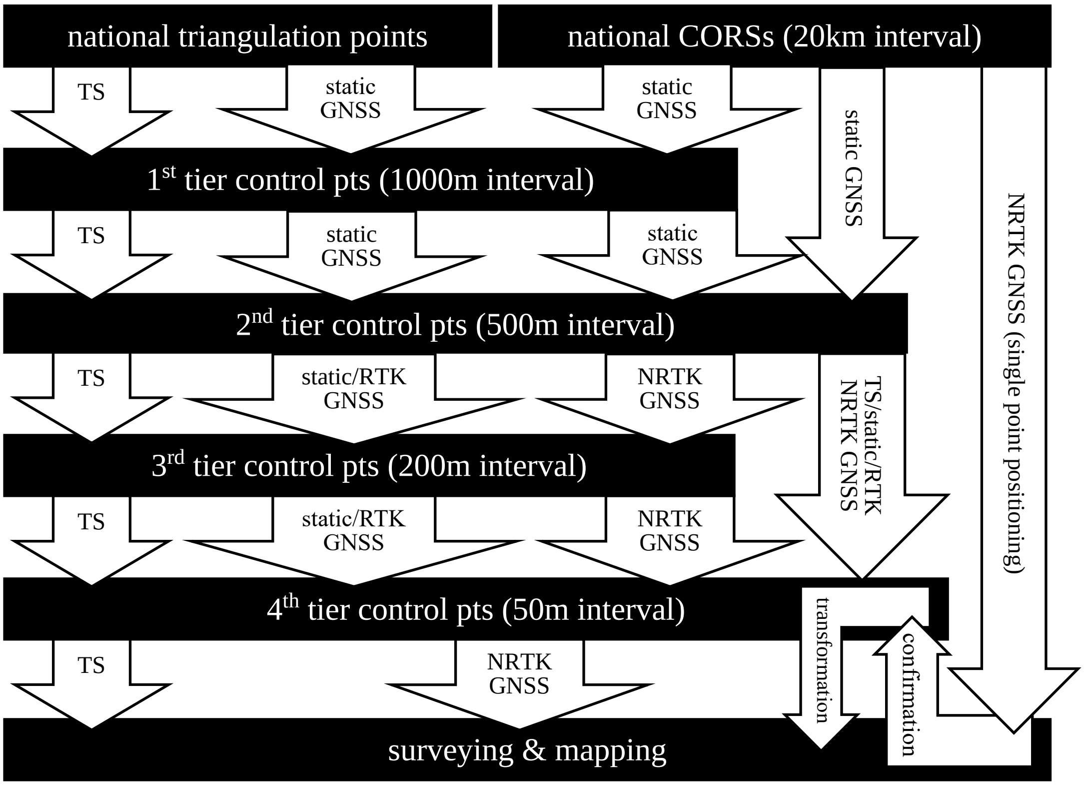

Figure 1. Hierarchical structure of control points

2.1.1 Quality control

Quality control is conducted strictly in various stages of field measurements, check calculations, and network adjustments. Repeatability between sets of observations is checked in field measurements by TS. Misclosures and ambiguity resolutions (GNSS) are checked in calculation after field measurements. After rigorous network adjustment (least squares adjustment) is applied, the residuals and standard deviations of angles, distances, baseline vectors, and coordinates are checked. However, quality criteria were derived allowing 10cm-tolerance of coordinates and are not suitable (too loose) for modern instruments.

2.2 Photogrammetric surveys

We focus on the issues of accuracy and resolution of aerial photos and maps in this paper as we just started the study on this field.

2.2.1 Standardized classification of map scale

Map information level is defined in place of map scale taking reciprocals of map scale. The standardized classification consists of the levels 250, 500, 1000, 2500, 5000, and 10000.

2.2.2 Quality criteria

Target accuracy of map coordinates is specified for each map information level using standard deviation, which was derived empirically from printed maps in condition that printed maps of a scale 1:2500 or smaller have 0.7mm accuracy on paper and that those of 1:500 or larger have 0.5mm.

Photographic scale and GSD (ground sample distance) are recommended for each map information level for film and digital camera respectively as shown in Table 1.

Table 1. Association of map information level with positional accuracy, photo scale, and GSD. B/H means the ratio of the baseline and the height of camera positions.

Map Information Level	Positional Accuracy (Horizontal)	Photographic Scale (Film Camera)	Ground Sample Distance (Digital Camera)
250	0.12m	–	–
500	0.24m	1:3000 – 1:4000	180*B/H – 240*B/H mm
1000	0.70m	1:6000 – 1:8000	360*B/H – 480*B/H mm
2500	1.75m	1:10000 – 1:12500	600*B/H – 750*B/H mm
5000	3.50m	1:20000 – 1:25000	1200*B/H – 1500*B/H mm
10000	7.00m	1:30000	1800*B/H mm

2.2.3 Survey method

Combined use of GCP and GNSS/IMU for the determination of the position/orientation of an aerial camera is instructed both for film and digital cameras. The use of CORSs of GSI are recommended as reference stations for kinematic GNSS. After the completion of the flight, *simultaneous adjustments*, bundle adjustments for the entire area of interest using a digital stereo plotter, are instructed. Film imageries must be digitized with a pixel size of 21μm or less before the adjustments.

2.2.4 Quality control

Quality control is conducted in various stages of GCP set-up, flight operation, camera calibration, and analysis of GNSS/IMU after the flight. Residuals of GCPs and intersection discrepancies of pass points must be examined after simultaneous adjustments.

3. Prevailing technologies in use for control surveys and photogrammetric surveys and challenges to modernizing the current GSOS

3.1 Prevailing technologies in use based on the nationwide CORS network in Japan

Modern technologies such as GPS/GNSS, digital photogrammetry, and digital mapping has been emerging since the last decade of 20th century. However, control points used in the survey were traditional national triangulation points --- there are 100,000 points --- and public control points, and GCP for aerial surveys were also set up using the traditional ones. No CORS data was provided at that time. GSI started in 1996 the operation of GEONET (GPS Earth Observation NETwork system), which is the nationwide CORS network in Japan consisting of more than 1,300 CORSs (Tsuji et al., 2017), and GEONET data has been available for public surveys since 2002 when a geocentric reference system was enforced by the amended Survey Act (GSI, 2004).

Provision of CORS data changed the way of public surveys in view of cost and time efficiency and GSOS has been updated to merge the emerging technologies into the traditional ones. GSOS helped to promote the use of the modern technologies though it has limitations to prescribe modern technologies in the old framework.

3.2 Control surveys

3.2.1 Limitation of accuracy of the national triangulation points

Though the national triangulation points are maintained by GSI particularly after the crustal/ground movements by earthquakes, the positional accuracy of most points remains at the level of 10cm (one sigma). GSOS is prescribed based on this accuracy. The improved performance of TS and GNSS and the accurate coordinates of CORSs of 2cm (Tsuji and Matsuzaka, 2004) are not reflected there.

3.2.2 Complicated descriptions of operation specification

Because control surveys based on the use of theodolite/EDM or TS and triangulation points are the basis of GSOS, the hierarchy of four-tier control points is still retained. On the other hand, various methods of GNSS observations (static, RTK, Network RTK, post processing kinematic, etc.) are introduced in GSOS and some of the method have exceptional association with the hierarchy by skipping the rank of tiers. GSOS has been updated by patchworks, which make it complicated and difficult particularly for beginners to understand GSOS.

3.3 Photogrammetric surveys

Though the current version of GSOS includes specifications regarding both film camera and digital camera, the exclusion of film camera is planned this year, which makes the GSOS less complicated.

3.3.1 Limitation of *nominal* map accuracy

GSOS specifies the target accuracy of maps (table 1), which appears to be much less accurate compared to the description of ASPRS 1990 Class 1 map in ASPRS Positional Accuracy Standards for Digital Geospatial Data (ASPRS, 2014). Taking an example of map information level 2500, the target accuracy is 1.75m in GSOS whereas ASPRS 1990 Class 1 of 1:2400 has the $RMSE_r$ of 0.849m. The target accuracy, i.e., the nominal accuracy of GSOS is almost the same level as the National Map Accuracy Standard of 1947 in USA also described in ASPRS (2014).

3.3.2 Quality criteria and control based on film camera and paper map

The target accuracy of maps in GSOS was defined based on the use of film cameras without GNSS positioning/orientation and the production of printed maps. It includes limitation in managing the interior/exterior orientation of camera and the elasticity of film and paper. While GSI promoted the use of digital mapping technology in 1990's and digital camera with GNSS/IMU in 2000's and merged them into GSOS, the target accuracy and the quality control remain the same.

GSOS defines the relationship between GSD of aerial photos and map information level.

The relationship assumes that the pixel size of digitized photos is 20μm though digital cameras currently in use have the pixel size of around 4-5 μm.

GSD for each map information level is not specified uniquely but by a broad range, e.g., from 15cm to 30cm for map information level 2500 assuming B/H ranges from 0.25 to 0.39, while map accuracy for each map information level is uniquely specified.

ASPRS (2014) also describes GSD by a broad range from 15cm to 30cm for 1:1200 ASPRS 1990 Class1 map, larger map scale than that of GSOS.

4. Proposed approaches to overcome the challenges

As mentioned above, the basis of GSOS consists of outdated technologies such as control surveys using theodolites/EDMs at triangulation points and photogrammetry using film cameras to make paper maps. This resulted in making products less accurate by employing modern technologies under the outdated quality control. In addition, GSOS has become complicated and difficult to understand because of the inclusion of obsolete and modern technologies together within the same context.

The basis of GSOS should be modernized to make full use of capability of modern technologies and to make GSOS concise and easy to understand by excluding obsolete technologies.

4.1 Establishment of a study group

Most of public organizations still use GSOS without any inconvenience, and if the government provided another "GSOS", it might appear as double standards.

In this background, we, as a private sector, set up a study group to develop new specifications, aiming at contributing to modernize GSOS. A study group consisting of academia and industry was established to identify the challenges, and to discuss and propose the solutions against them.

We confine ourselves in putting basis on modern technologies used dominantly today: for control surveys, exclusively use of GNSS, CORS and TS; for aerial surveys, exclusively use of digital cameras and digital geospatial data.

4.2 Comprehensive study on control surveys

4.2.1 Accuracy analysis of TS

The Japan Association of Surveyors is one of the registered inspection agencies for survey instruments and survey results. The collection of inspection data indicates that 94% of TS in use have the angle reading unit of 5" (arc seconds) or less while GSOS specifies four classes of TS. We take TS of 5" reading unit for the further analysis. The inspection data and field experiments statistically revealed that the uncertainty of a pair of a horizontal angle observation is 2.5" and that the uncertainty of distance measurements derived from 2m-, 150m-, 200m-, and 400m-baseline is 1.3mm or less, which meets the nominal specification of 1-2mm+2ppm*D announced by manufacturers.

From the field experiments, we found that the centering error of a TS is 0.3mm and that of a mirror 0.6mm, both of which are unexpectedly small but still affect the angle and distance measurements and should be considered particularly for short distance.

Error propagation for a single route open traverse (Figure 2) is formulated as

$$M_n{}^2 = n \cdot dS^2 + \sum_{k=1}^{n} kS_k^2\, d\beta^2 + 2 \cdot \sum_{k=1}^{n-1} kS_k \sum_{j=k+1}^{n} S_j \cos(T_j - T_k) d\beta^2 \quad \cdots (1)$$

where

M_n: horizontal root mean square error at point n,
n: number of unknown points (or number of lines),
S_i: distance between point (i-1) and point i,
dS: uncertainty in a distance measurement,
β_i: included angle between point (i-2) and point i at point (i-1),
$d\beta$: uncertainty in an angle measurement,
T_i: grid bearing to point i at point (i-1), and

$$T_j - T_k = \sum_{i=k+1}^{j} \beta_i - (j-k)\pi$$

In a specific case of an equidistant traverse where $S_i \equiv S$, equation (1) is reduced to

$$M_n{}^2 = n \cdot dS^2 + \frac{n(n+1)}{2} S^2 d\beta^2 + 2 \cdot \sum_{k=1}^{n-1} k \sum_{j=k+1}^{n} \cos(T_j - T_k)\, S^2 d\beta^2 \quad \cdots (2)$$

When a traverse forms a straight line where $T_j = T_k = T$, equation (2) is further reduced to

$$M_n{}^2 = n \cdot dS^2 + \sum_{k=1}^{n} k^2\, S^2 d\beta^2 \quad \cdots (3)$$

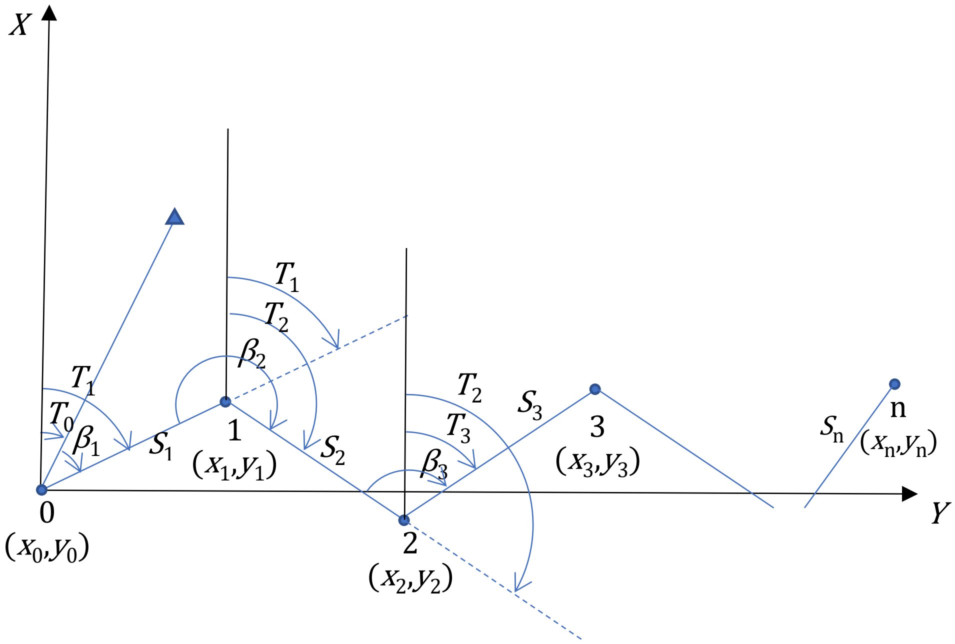

Figure 2. Illustration of a single route open traverse

Using equation (2), we made simulations of error propagation for the case of single route traverse of 500m with distances between neighboring points of 50m, included angles of 120° through 180° (degrees), the uncertainty of an angle measurement of 2.5”, uncertainty of a distance measurement of 1.3mm, and centering errors of 0.3mm (TS) and 0.6mm (mirror). The simulations show that the estimated errors range from 20mm to 25mm (1 σ). Figure 3 shows an example of the simulations when a traverse forms a straight line of 500m length and distances between neighboring points are equally 50m using equation (3). If a traverse is made closed and the coordinates of the traverse points are adjusted with the start and end points fixed, the errors at the traverse points will be smaller. This implies if the coordinates of the start and end points of a traverse are determined with an accuracy of 20mm or less, the coordinates of unknown points located along the route can determined within 20mm accuracy.

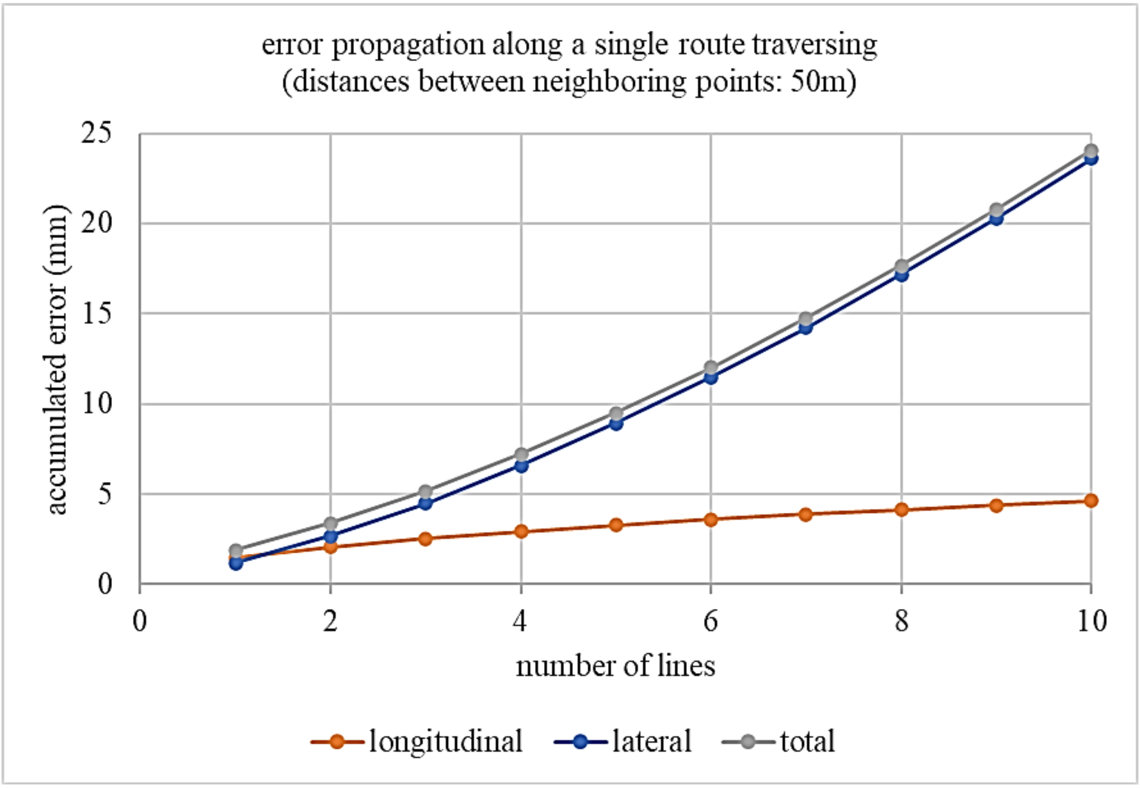

Figure 3. An example of simulation of error propagation. Length of a traverse: 500m, distances between neighboring points: 50m, included angles: 180°, uncertainty of an angle measurement: 2.5”, uncertainty of a distance measurement: 1.3mm, centering errors of TS: 0.3mm and those of mirror: 0.6mm.

4.2.2 Accuracy analysis of GNSS

The collection of the inspection data shows that 96% of inspected GNSS receivers have dual frequency function and that the measurement uncertainties of static-mode GNSS for 10km baseline are 6mm for NS and EW components and 26mm for vertical component (Figure 4). It also shows that the uncertainties of network RTK GNSS for 200m baseline are 5mm for NS and EW and 11mm for vertical (Figure 5). Because no data is available for estimating the uncertainties of static GNSS for 200m baseline in the inspection data, they are estimated based on the experimental uncertainties of network RTK GNSS with the use of nominal uncertainties announced by manufacturers. The ratio of nominal uncertainties of static GNSS vs network RTK GNSS calculated for 200m baseline is found to be around 1: 2 to 1: 3, suggesting that the uncertainties of static GNSS for 200m can be 2-3mm for horizontal and 4-5mm for vertical. The uncertainty for 200m is statistically significantly smaller than those for 10km and this result should be taken in the weights for network adjustment when the network consists of baselines of the lengths from 200m to more than 10km, which are seen in public surveys.

Though network RTK GNSS generally shows good results, it shows RMSE of 40mm or more, having repeatability, at a certain observation site in our field experiments (Figure 6). The cause of this anomaly is not identified and the adopt of this mode in the study is pending at the moment.

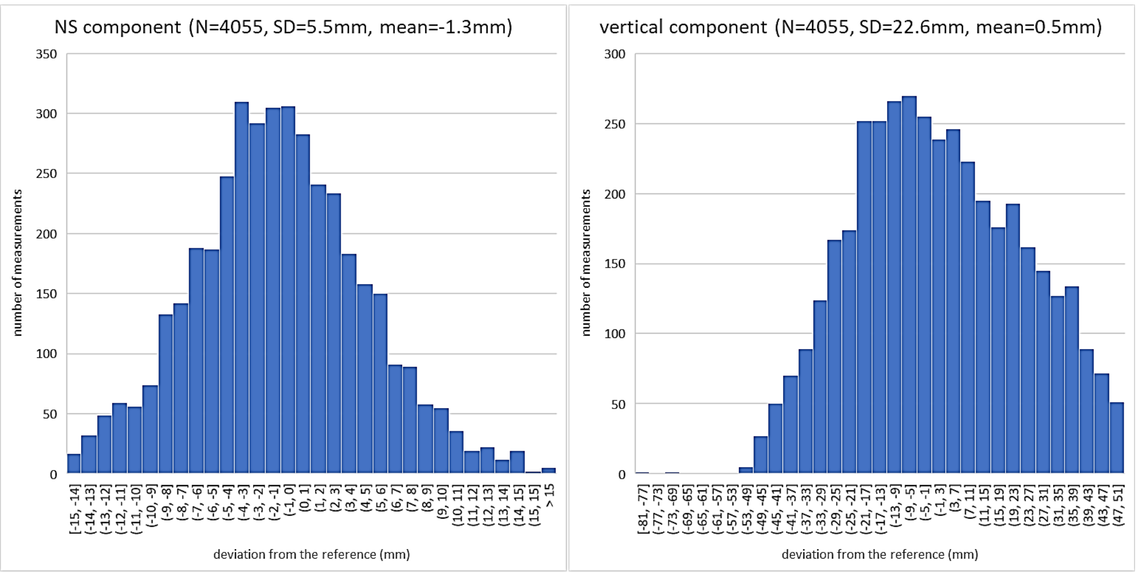

Figure 4. Deviations of static GNSS measurements from the reference value, measurements which are obtained from the inspection. (left) NS component, (right) vertical component.

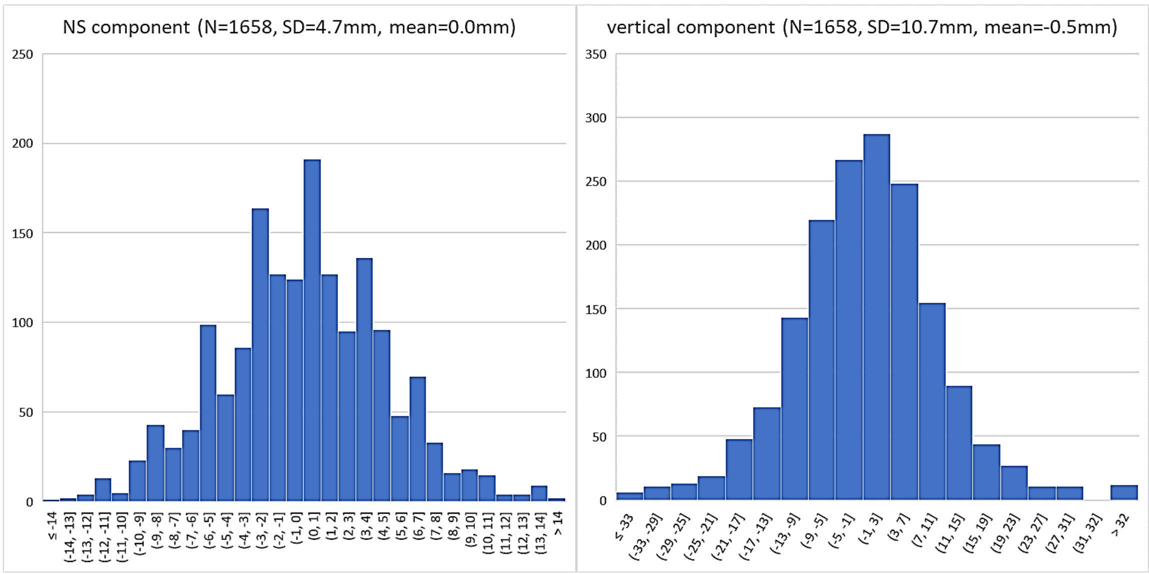

Figure 5. Deviations of network RTK GNSS measurements from the reference value, measurements which are obtained from the inspection. (left) NS component, (right) vertical component.

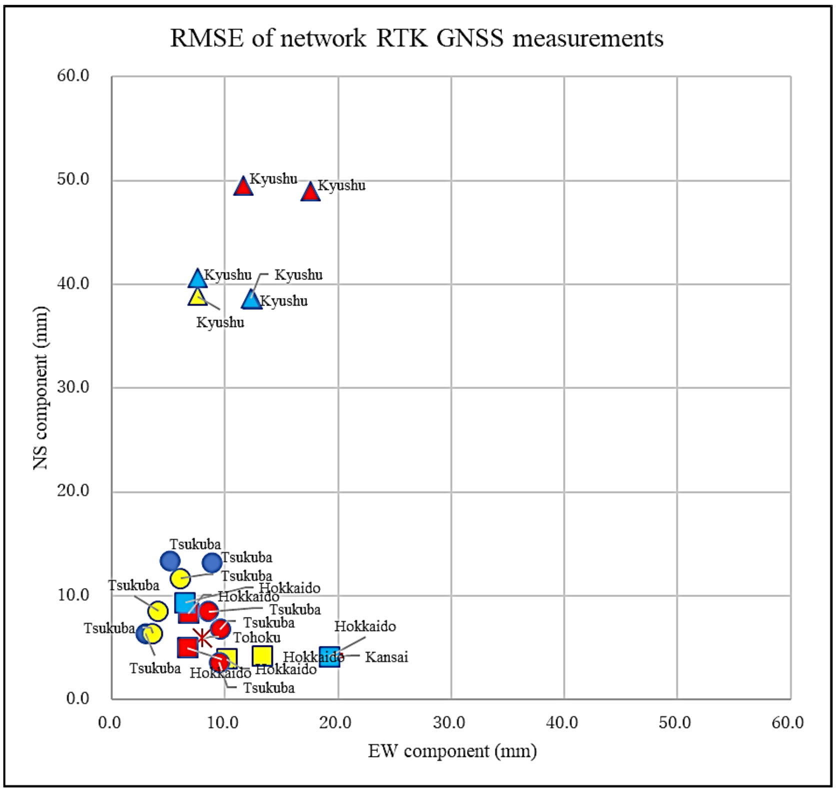

Figure 6. RMSE of network RTK GNSS measurements. Colors of marks indicate data providers of network RTK and shapes of marks indicate locations of measurements. Repeatable large errors are seen at Kyushu (triangles in the graph).

4.2.3 Restructured hierarchy of control points

GSOS defines four-tier hierarchy of control points under the national triangulation points as well as GEONET, the national CORS. We currently propose simplified two-tier hierarchy structure (Figure 7). The first-tier points are set up by using only GNSS and CORS with the distances between points of 200m to 1000m without reference to any national triangulation points nor public control points that are less accurate. The second-tier points are set up by using TS with reference to the first-tier points and with the interval of 50m. This simplifies the hierarchy of control points and the associated survey methods. In addition, the elimination of triangulation points and the simplified hierarchy expectedly lead to determining control points with an accuracy of few centimeters.

4.2.4 Revised weights for network adjustments

Weights for network adjustments should be reconsidered to meet with the proposed procedures. Some experimental calculations show that the current weights instructed in GSOS are not appropriate for the proposed procedures. In case of traversing by TS, weights recommended in GSOS work for 10cm accuracy but not for few centimeters. Assumed variances (i.e., the reciprocals of weights) for angles and distances in GSOS are much larger than those derived from current instruments. In case of GNSS, GSOS recommends a set of fixed weights corresponding to the uncertainties of 4mm for NS and EW components and 7mm for vertical component. GSOS does not assume the network consisting of various lengths of baselines while our proposal includes 200m through 20km baseline length. Using our field experiment data for the network consisting of various lengths of baselines, we made the network adjustments with a set of fixed weights recommended in GSOS and found that the adjusted coordinates have statistically significant differences from those obtained by TS in both horizontal and vertical components. We are trying to find better solutions such as the determination of appropriate uncertainties applied for weights in GNSS network adjustments using data from inspections and experiments.

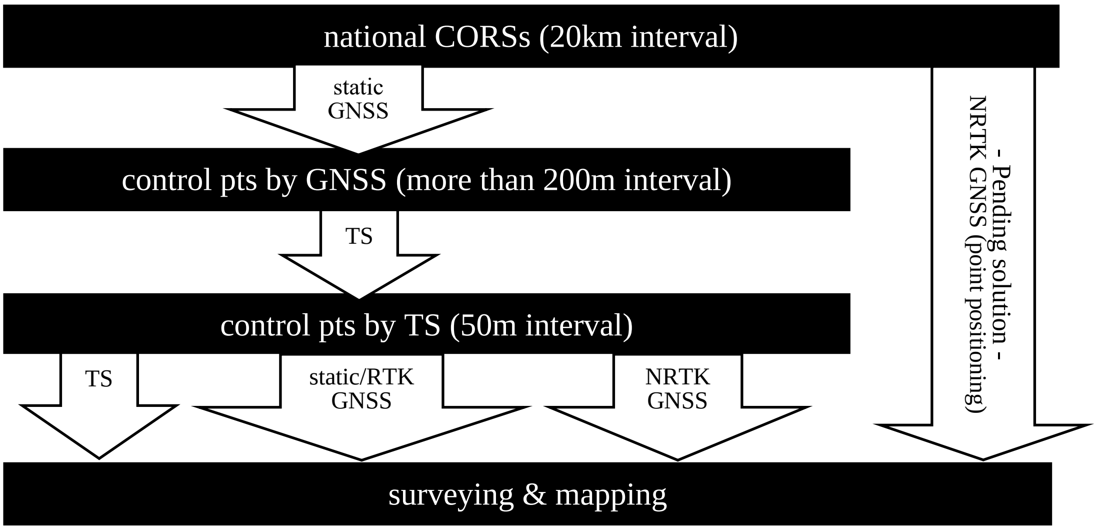

Figure 7. Proposed hierarchy structure of control points

4.3 Comprehensive study on photogrammetric surveys

4.3.1 Ground sample distance (GSD) implemented in practical public surveys

Though GSOS specifies a wide range of GSD for each map information level, the collection of inspection data shows the limited numbers of GSD. For instance, GSD of 20cm is prominent to produce map information level 2500. This suggests the relation between GSD and map information level should be more specific.

4.3.2 Quality criteria of aerial photos based on GSD

GSD of 20cm above mentioned may be excessive compared to ASPRS (2014), which shows GSD of 13.8 to 27.5cm corresponds to 1:1100 of ASPRS 1990 Class 1 map. Determination of suitable GSD will need experiment and be examined in future work.

4.3.3 Positional accuracy of 1: 2500 maps in practice

Though the nominal accuracy seems less accurate, the evaluated accuracy of map information level 2500 was proved to be more accurate. Koshimizu and Murakami (2014) evaluated digital maps of the level 2500 from public surveys and revealed the $RMSE_r$ of the discrepancies between map coordinates and corresponding coordinates measured by Network RTK GNSS is less than 0.8m. This indicates that the positional accuracy of maps is practically well achieved comparable to ASPRS (2014). The quality criteria and control in GSOS should be modified to reflect the current situation of public surveys.

4.3.4 Revision of the relationship between positional accuracy and map scale

To revise the relationship between positional accuracy and map scale, the error budget should be conducted through the entire process of mapping including GCP setting, aerial triangulation/adjustment, determination of GSD, and plotting. In developing new specifications, we aim at the same level as (or better than) ASPRS (2014).

5. Present progress and future prospect

Appropriate weights for network adjustments of control surveys both for traverse by TS and GNSS/CORS observations are being examined. In case of GNSS/CORS, weights should be changed depending on baseline length. We expect to obtain an appropriate set of weights soon. On the other hand, we have not found appropriate weights for traverse by TS so far.

Study on an appropriate relationship between GSD of aerial photos and positional accuracy of maps has just begun. We are planning to make theoretical and experimental consideration this year.

While retaining GSOS which works well today, we will modernize it for the future needs for accuracy.

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BIOGRAPHICAL NOTES

Mr. MURAKAMI Masaki has been Vice President of the Japan Association of Surveyors since 2019. He worked for the Geospatial Information Authority of Japan and retired in 2015 as Deputy Director General. He works for Pasco corporation after the retirement.

CONTACTS

Mr. MURAKAMI Masaki
Japan Association of Surveyors
Koishikawa 1-5-1, Bunkyo-Ku,
Tokyo, 112-0002
JAPAN
Tel. +81-3-3815-5751
Email: murakami@jsurvey.jp
Web site: https://www.jsurvey.jp/eng.htm