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VLBI-GPS Collocation Method at Geographical Survey Institute

Shigeru Matsuzaka, Yuki Hatanaka, Keizo Nemoto, Yoshihiro Fukuzaki, Kyoko Kobayashi, Kaoru Abe, Tadayuki Akiyama

Geographical Survey Institute

Contact author: Shigeru Matsuzaka, e-mail: shigeru@gsi.go.jp

Abstract

We report our effort to establish a precise tie between VLBI and GPS. For local-tie survey, we employed conventional survey method using total-stations and leveling, and to pursue the precision, introduced permanent observation monuments for ground survey and Cateye reflector for the target on the VLBI antenna. With these instruments and careful measurements, 3D coordinates of antenna reference point were determined with sub-mm error at GSI-Tsukuba and Aira stations.

1. Introduction

Geographical Survey Institute (GSI) now operates and maintains five VLBI stations for international and domestic experiments: Shintotsukawa, Tsukuba, Kashima26, Aira and Chichijima. The results of these experiments were utilized in establishing Japan's new geodetic datum compatible with ITRF and provided a fundamental set of coordinates in the reference frame. Densification was accomplished by connecting nationwide GPS (GEONET) solution to the VLBI results [3]. Although their relationship was compared and assured within a few cm, to further utilize the space-geodetic networks and detect smaller signals for the study of geodesy, geophysics and astrometry, millimeter-level collocation and inter-comparison of different techniques are required. In our earlier study [2], we tried to establish the tie using GPS measurements permanently attached to the 32 m dish. The accuracy of vertical component was not satisfactory due probably to GPS antenna's phase effect. In this paper, we adopted a conventional survey method to improve the accuracy of local-tie and the reliability of observations (see, e.g. [1]).

2. Method and Instrumentation

Conventional terrestrial surveying method was chosen for the local-tie survey: electro-optical measurements for distance and angle and leveling for height. Introduction of a specially designed ground monument and Cateye reflector must be highlighted in the improvement of accuracy and efficiency of the survey (see below). Although high precision surveying instruments are recommended, we used commercially available instruments, which are good enough but not the very best of all.

3. Procedures

Procedures for the VLBI-GPS tie would be as follows;

- Determine the relations between ground monuments and GPS reference points by distance and angle measurements and/or leveling.

- Determine from the monuments around the VLBI antenna the positions of Cateye reflector on the dish when the antenna points to various directions.
- Assume the trace of the target is a sphere and estimate the position of its center. If necessary, make corrections for VLBI antenna deformations due to temperature change and gravity.
- Calibrate the GPS antenna's phase variation.
- Make GPS measurements with a point in the local network and a point outside of it for orientation of the network.
- Transform the local network to align with a global reference system by rotating it using the direction obtained above and deflection of the vertical.

4. Local Survey

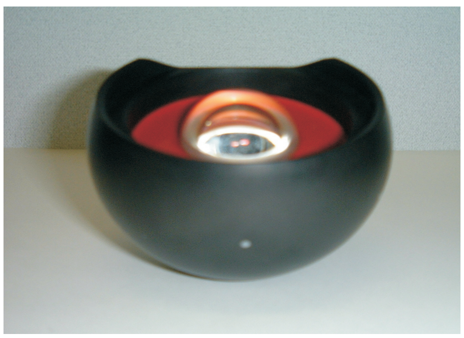
4.1. Construction of Ground Monuments

Our newly designed monument is a hollow stainless steel pillar with outer stainless steel cover sandwiching styrofoam sheet. On top of it are an adaptor for survey instruments and metal plates to hold them down (see Figure 1).

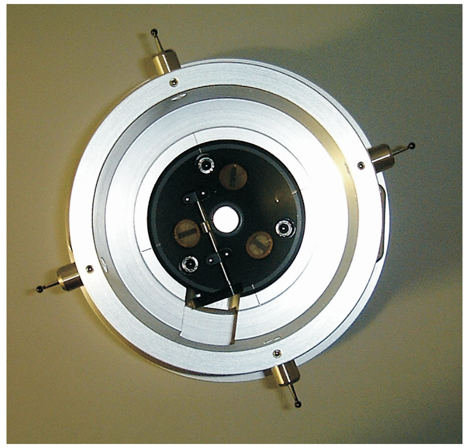
Figure 1. **GSI Ground Monument**

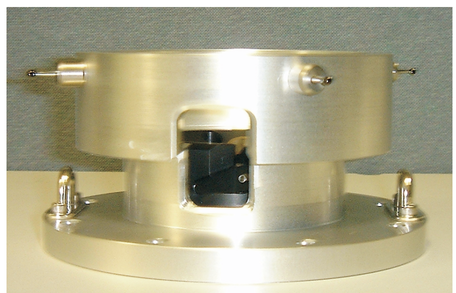
4.2. Introduction of Cateye Reflector as a Target on the Antenna

The Cateye is a half-sphere reflector with much wider range of entry angle (120°) than a conventional plane mirror reflector ($< 60°$), which helps the measurements from fixed ground monuments. It is held in a magnet support remodeled for angle measurements as well as distances to serve as a target on the VLBI antenna (see Figure 2).



Leica Cateye Reflector. Entry angle: ±60°, centering error of housing and reflector: <0.01mm, dimension of hemispherical housing: 75±0.05mm.





Magnet Support for Cateye, pins for angle measurement. Diameter: 170mm, height: 79mm, weight: 1.55kg

Figure 2. Cateye and its Support

5. Observations and Data Reduction

A survey was performed with total stations to measure distances, horizontal and vertical angles to tie the ground monuments and target positions. Leveling was also carried out for precise height measurements. The Cateye was mounted on the supporting structure of the dish. The location of the Cateye must be at rigid part of the antenna and simultaneously visible from at least two ground monuments at various positions of the antenna. Observations were made at around 20 antenna positions (4-6 azimuths and 4-5 elevations). List of instruments we used are in Table 1.

Table 1. Instruments and Accuracy

Instrument and Type	**Accuracy(distance)**	**Accuracy(angle: seconds)**
SOKKIA NET2B: Total Station	2.0mm+2ppm*D	2.0
TOPCON GTS-700: Total Station	2.0mm+2ppm*D	1.0
WILD T2: Theodolite		
WILD N3: Tilting Level		

Network solution and the position of VLBI antenna reference point are obtained in an arbitrarily chosen 3D Cartesian coordinate system, (u, v, w). In this paper, 3D positions of ground monuments and antenna targets were calculated by a (plane coordinate) network adjustment program of triangulation and vertical angles, which is standard survey reduction software in GSI. One of the ground monuments was chosen as the origin of w is tangent to the local vertical, and the direction from the origin to another monument is contained in uw or vw plane. A least squares fit program was used to determine the center of a sphere on which the target must be positioned. Here, we employed the following method.

Let $\vec{u}_c = (u_c, v_c, w_c)^T$ be the position vector of the center of the sphere and $\vec{u}_0 = (u_0, v_0, w_0)^T$ be the vector from the center to the antenna target when the antenna is at $(az, el) = (0°, 90°)$, ω_x, ω_y, ω_z are small rotation angles of antenna frame with respect to the topocetric frame (east, north, up) and ϕ_0 is the angle between v-direction of uvw frame and the north of antenna frame. The mathematical model is

$$\vec{u}_i = \vec{u}_c + R_3(\omega_z)R_2(\omega_y)R_1(\omega_x)R_3(-(\phi_i + \phi_0))^{-1}R_1(-(90 - \theta_i))^{-1}\vec{u}_0 \quad (1)$$

where $\vec{u}_i = (u_i, v_i, w_i)^T$ is the ith position of the target when the antenna points to (ϕ_i, θ_i), and

$$R_1(\alpha) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\alpha & sin\alpha \\ 0 & -sin\alpha & cos\alpha \end{pmatrix}, R_2(\alpha) = \begin{pmatrix} cos\alpha & 0 & -sin\alpha \\ 0 & 1 & 0 \\ sin\alpha & 0 & cos\alpha \end{pmatrix}, R_3(\alpha) = \begin{pmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

are rotation matrices. We took nine independent parameters as, for example, $\vec{u}_c = (u_c, v_c, w_c)^T$, u_0, $d_0 = (v_0^2 + w_0^2)^{1/2}$, $\theta_0 = arctan(v_0/w_0)$, $\phi_0 - \omega_z$, ω_x and ω_y.

As equation (1) is nonlinear in some of the parameters, it was linearized to get the observation equation and solved with iteration.

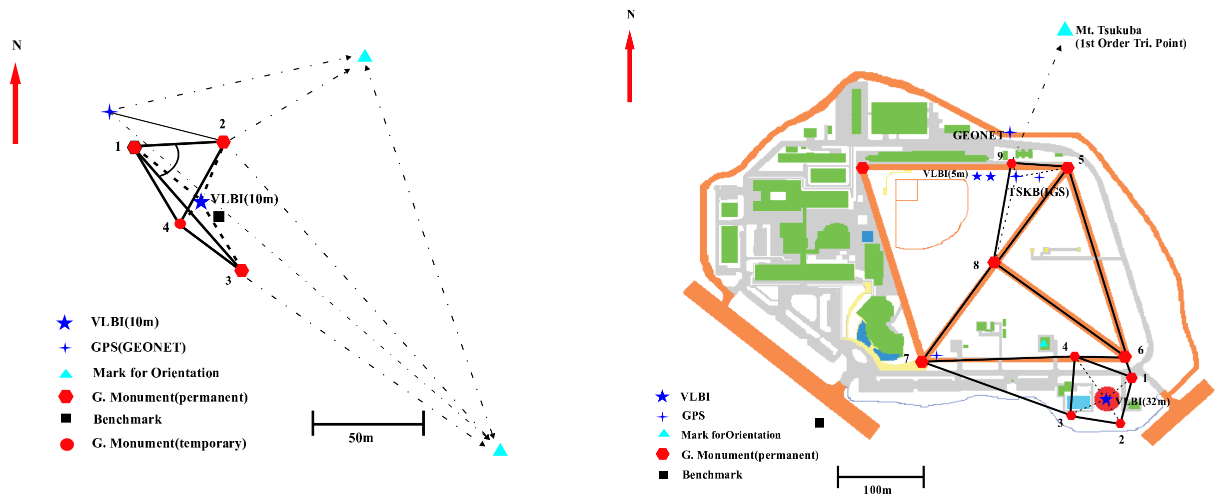
6. Results

6.1. Aira

The survey was performed in February - March 2001. The network is shown in Figure 3 left. Three new monuments were used along with a temporary monument. The network includes 2 points for orientation and 1 benchmark. There were 18 target positions on the 10m dish for antenna survey. For network adjustment, 1 set of horizontal angle was used with distance measurements to strengthen the network because Point 2 and 3 were not mutually visible. Point 3 was chosen as origin and 3 to 1 direction as v-axis. Leveling data was not used in the calculation. The position of VLBI reference point was determined as $(6.5431, 41.1339, 9.0602)$ with s.e. of $(0.0007, 0.0006, 0.0011)(unit : m)$.

6.2. Tsukuba

The survey was performed in March 2001. Network is shown in Figure 3 right. Four new monuments around VLBI (32m) and one near GPS (TSKB) were used along with four existing monuments used for instrument calibration. The network includes one triangulation point for orientation (Mt. Tsukuba) and one benchmark. There were 20 target positions on the 32 m dish for antenna survey. Point 4 was chosen as origin and 4 to 6 direction as u-axis. Leveling was not yet performed. The position of VLBI reference point was determined as $(35.9808, -51.3111, 18.3028)$ with s.e. of $(0.0005, 0.0005, 0.0010)(unit : m)$.



Aira Local Network **Tsukuba Local Network**

Figure 3. Local Networks

7. Conclusions and Future Works

By introducing the Cateye reflector and new ground monuments, we realized the local tie between VLBI and GPS with sub-mm level at two of our VLBI sites and established our standard procedures for it. Future work will include completion of survey at Tsukuba and other VLBI stations, actual comparison of space-geodetic data, annually or seasonally repeated observations to reveal any periodic/systematic variations, and expanding our measurements to collocate with other space-geodetic techniques.

References

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