

A Dual Checking System for Determining the Telescope Reference Point - How to improve vertical precision -

Jun Amagai¹, Futaba Katsuo¹, Hitoshi Tamura² and Hisayoshi Kikukawa³

¹ Keystone Project Team, Communications Research Laboratory
4-2-1 Nukui-Kita, Koganei, Tokyo, 184-8795 JAPAN

² Kokusai Kogyo Co. Ltd.

³ Hitachi Ltd.

Abstract

Our new calibration method for measuring system delay and determining the position of the telescope reference point reduces the vertical component error by using benchmarks under the telescope. Here we explain in detail our method for benchmark ranging.

1. Introduction

To tie the geodetic results of SLR (satellite laser ranging) with the results obtained using other space geodetic techniques, it is necessary to know the position of the telescope reference point in terms of local coordinates. Because the difficulty of setting a target just on the telescope reference point makes it difficult to use conventional survey techniques to determine this positions, we developed a new method (Katsuo, et al., 1999). In this new method we use multiple ground targets and range them in the same manner as in the usual laser ranging to a satellite. Using the ranging data for the ground targets, we can simultaneously determine system delay and the three-dimensional coordinates of the telescope reference point.

The errors of the estimated position and system delay depend very much on the locations of the targets. If the targets are distributed only horizontally as shown in Figure 1, the error ellipsoid is elongated along the vertical direction as shown in Figure 2. This elongation is thought to be caused by coupling of the estimation parameter of the vertical component of the position with that of the system delay in observation equation. To reduce this coupling, we should get range data for vertically distributed targets. So we introduced benchmarks located just under the telescope (Figure 3). They enable us to greatly reduce the vertical error as well as system delay error (Figure 4).

In this paper, we describe how the benchmarks are ranged, how the range data obtained for benchmarks is analyzed, and how the position of the pentagonal prism required for sighting benchmarks is determined.

¹amagai@crl.go.jp

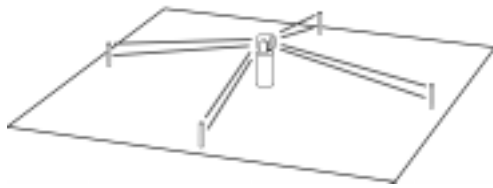


Figure 1. Eight targets distributed around the telescope. The distance between each pillar and the telescope is 15 m, the height of the telescope reference point is 5.5 m, and two targets (heights 2.5 m and 1 m) are used for each pillar.

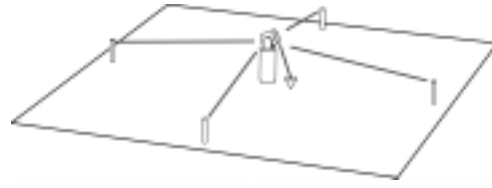


Figure 3. Four targets distributed around the telescope and one benchmark under the telescope. Distances and heights are the same as in Figure 1 except that only one target (height 2.5 m) is used for each pillar. The height of the benchmark is 0.1 m.

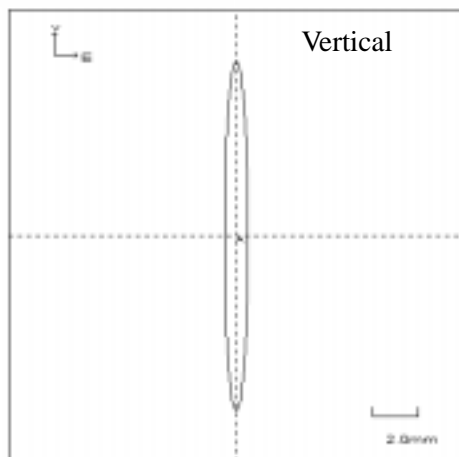
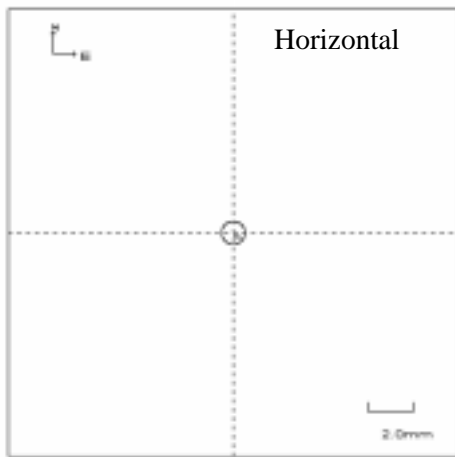


Figure 2. Estimated errors (horizontal and vertical) for the conditions shown in Figure 1. One-way ranging error is assumed to be 1 mm. Error of the estimated system delay is 1.9 mm.

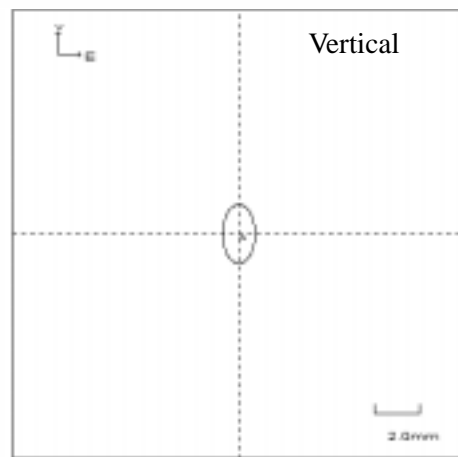
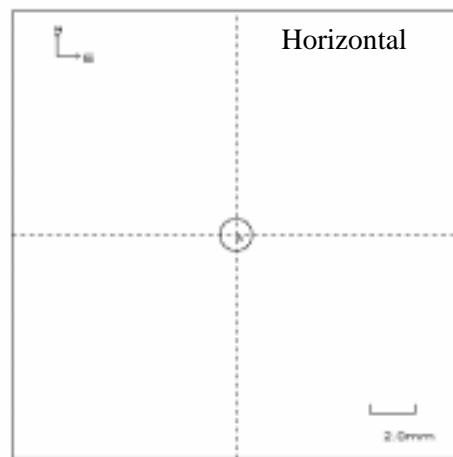


Figure 4. Estimated errors (horizontal and vertical) for the conditions shown in Figure 3. One-way ranging error is assumed to be 1 mm. Error of the estimated system delay is 0.6 mm.

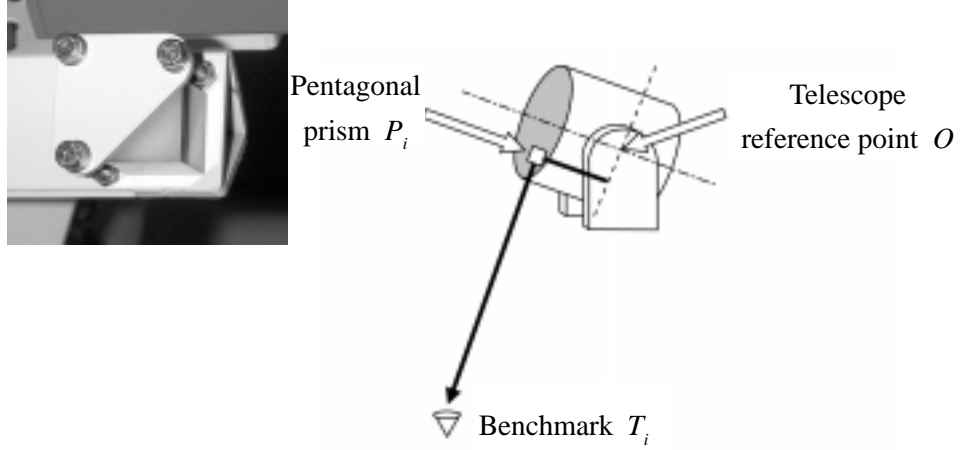


Figure 5. Pentagonal prism for bending the laser beam 90 degrees.

2. How to range benchmarks

Because the lowest elevation angle our telescope can reach is -20 degrees, we cannot sight benchmarks under the telescope directly. We therefore use a pentagonal prism to bend the laser beam 90 degrees (Figure 5). The observation equation for estimating telescope reference point and system delay is

$$\rho_i = \sqrt{\left\{ (T_i)_x - O_x - (\overrightarrow{OP}_i)_x \right\}^2 + \left\{ (T_i)_y - O_y - (\overrightarrow{OP}_i)_y \right\}^2 + \left\{ (T_i)_z - O_z - (\overrightarrow{OP}_i)_z \right\}^2} / C_{air} + \delta + \delta P_i \quad , \quad (1)$$

where the index i indicates the i -th target, ρ is the ranging data (one-way time of flight), T is the position vector of ground targets (pillars and benchmarks), O is the position vector of the telescope reference point (estimation parameter), \overrightarrow{OP} is a vector pointing from the telescope reference point to the pentagonal prism for the case of benchmarks ranging, C_{air} is the speed of light in air, δ is system delay (estimation parameter), and δP is the time required for a wave front at the telescope reference point to reach the reference point of the pentagonal prism (intersection of normal lines through the center of each prism aperture) for the case of benchmarks. We cannot solve observation equation (1) correctly without taking account of the refractive index of the prism material and of the excess path delay due to the prism.

We treat the refractive index of the prism material and the excess path delay as if they were included in δP so that the equation (1) can be used for ranging both pillar and benchmark. So δP for a benchmark as the i -th target can be expressed as

$$\delta P_i = \left(\overrightarrow{OP}_i \bullet e_{telescope\ i} \right) / C_{air} + L_1 / C_{glass} - L_2 / C_{air} \quad , \quad (2)$$

where $e_{telescope\ i}$ is a unit vector pointing in direction of the telescope which sights benchmarks via prism, L_1 and L_2 are the ray paths shown in Figure 6, and C_{glass} is the speed of light in the prism material.

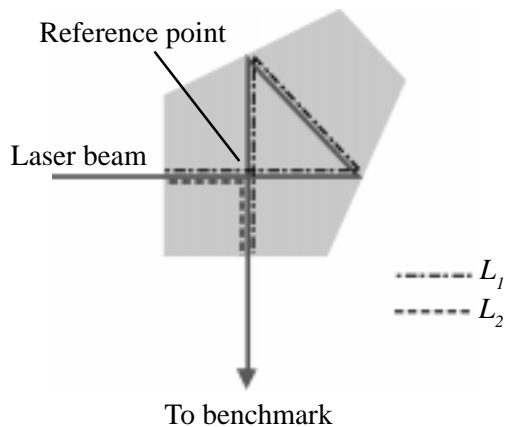


Figure 6. Ray paths in the pentagonal prism.

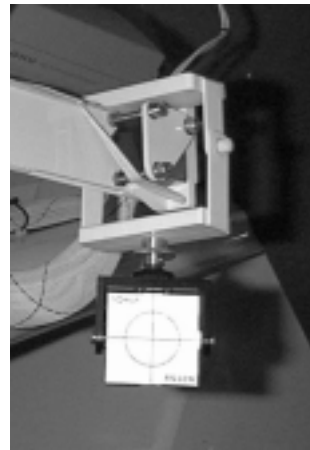


Figure 7. Special target hanging just under the prism.

3. Prism position survey

Each term on the right-hand side of equation (1) except the estimation parameters should be measured precisely in advance. So we should measure the position of the reference point of the prism for each benchmark. Because it is impossible to measure the reference point of the prism directly, we use a special target that hangs just under the point (Figure 7). We determine the position of this target from outside the telescope dome by using a total station NET2B. By using triangulation and trilateration integrated network method (Xia, et al., 1999), we can determine the special target position precisely and then get the position of the reference point of the pentagonal prism by using a vertical offset correction.

4. Conclusion

We have been accumulating ground target ranging data and plan to evaluate the effectiveness of the method described here. We will then use this method to routinely monitor the position of the telescope reference point and the system delay. This data will be very useful for checking the condition of the system and for making the system more reliable.

References

- Katsuo, F., Otsubo, T., Amagai, J., and Nojiri, H., "A Dual Checking System for Determining the Telescope Reference Point," in this issue.
- Xia, S., Tamura, H., Hasegawa, H., Ooizumi, J., Kunimori, H., Amagai, J., and Kikukawa, H., "Local Tie at the Key Stone Sites," in this issue.