The Optical Measuring System of Universal Time: Digital Zenith Tube

Hongbing Cai*, Jingsong Xu1, Shaojie Chen2,3
1 Jiangsu Normal University, Xuzhou 221116, China
2 National Time Service Centre, Chinese Academy of Sciences, Xi’an 710600, China
3 Key Laboratory of Time and Frequency Primary Standards, National Time Service Center, Chinese Academy of Sciences, Xi’an 710600, China
Email: hbcai@jsnu.edu.cn

Abstract. Universal Time is one of the Earth Orientation Parameters, which reflects the Earth’s rotation. Universal Time is the necessary parameter to build up the connection between the celestial reference frame and the terrestrial reference frame. In present, to measure Universal time relies mainly on Very Long Baseline Interferometry technique, but the period of gaining the observing result is a few weeks later although its measuring accuracy is very high. For shortening the data period and cutting the cost of observations, National Time Service Center constructed the Digital Zenith Tube net. In this paper, we state the structure of Digital Zenith Tube, its observation principle, observing features, observing process, and the system composing of the observing net. The Digital Zenith Tube net can also measure the deflections of the vertical of local stations which is an important parameter in the geodesy.

Keywords: Universal Time; UT1; Digital Zenith Tube; VLBI

1. Introduction

Universal Time (UT1) delegates the rate of rotation of the Earth, which is widely used as the fundamental time measurement system before 1960. The function of UT1 as the fundamental time measurement system was then replaced by the Ephemeris time and atomic time separately. Although UT1 is not used as the timebase to definite the “second” any more, it is indispensable for the producing and maintaining of the Coordinated Universal Time (UTC). In addition, UT1 reflects the spin angle of the Earth. UT1 together with the polar motion, precession, and nutation are called the Earth Orientation Parameters (EOP) [1]. EOP is the necessary parameter to realize the convert between the celestial reference frame and the terrestrial reference frame, which is important for the field of the space technique application.

Currently, the measuring method of UT1 mainly relies on the techniques of Very Long Baseline Interferometry (VLBI), Global Navigation Satellite System (GNSS), Doppler Orbitography and Radio positioning Integrated by Satellite (DORRIS), Lunar Laser Ranging (LLR), and Satellite Laser Ranging (SLR) [2]. The ultimate resolving results of UT1 are published by the organization of International Earth Rotation Service (IERS) by the bulletin A and bulletin B regularly. The accuracy of UT1 announced by IERS is about 20 microsecond. Before the 1980s, the method of resolving UT1 in the international is by the optical observations, for example, the transit instrument, the astrolabe, and photographic zenith tube (PZT), etc. Because VLBI has the high accuracy with milli-arcsecond in the astrometry, VLBI is used as the main observation method to resolve the UT1 after 1980s [3]. The Digital Zenith Tube (DZT) is manufactured in 1990s in the international [4]. The cost of construction...
and maintenance of the observation net of DZT is much less than the cost of VLBI although the measuring accuracy of DZT is lower than the accuracy of VLBI. In addition, the period of obtaining the result by DZT is shorter than the one of VLBI, but also the deflection of the vertical can be measured directly by DZT [5], whose accuracy is the highest in all the measuring methods of the deflection of the vertical. The deflection of the vertical reflects the difference between the gravity vector of the Earth’s surface and the ellipsoidal surface normal, which is important to the determination of gravity field [6]. Due to the features of DZT, National Time Service Center (NTSC) of Chinese Academy of Sciences (CAS) constructed the DZT net, and launched the research of measuring UT1 by DZT.

In the traditional optical system of measuring UT1, the accuracy of PZT is the highest because PZT only observes the sky coverage near the zenith, and then the effects due to the atmospheric refraction is the smallest. Due to the developing of CCD and the improvement of the electron-inclinometer performance, National Astronomical Observatory (NAOC) of CAS devised a new DZT [7], which is much smaller in the volume, and has the higher automation level in contrast to the traditional PZT. Although the accuracy of DZT is 50 times lower than the one of VLBI, the DZT is easy to operate, the cost of operation and maintenance is lower by two orders than VLBI, and the period of obtaining the UT1 is much shorter than VLBI. NTSC has constructed the DZT net, which can be controlled remotely by the internet.

2. The Observing Features of DZT

2.1. The Structure of DZT
The diameter of objective lens of DZT is 20 centimeter, through which the starlight arrive the plane mirror at the bottom of the tube, then the starlight is reflected to the angle mirror in the tube above, the starlight is then reflected to CCD. The focal length is 1.2m, and the field of view is about 1 degree.

Figure 1 shows the picture of DZT. The black surface is the tube, which is made of the aluminium alloy material. The length of tube is 516 millimeter, and the tube is set on the rotating platform. The controlling accuracy of rotating platform is 2 arcsecond. The drive system composed of high-speed stepping motor and harmonic gear can control DZT to rotate between the 0 degree and 180 degree positions. The controlling accuracy of rotating axis is better than 1 arcsecond. The electro-inclinometer is on the right side of tube, CCD is on the left side of tube.

![Figure 1. The physical map of DZT.](image)

2.2. Observation Principle of DZT
DZT takes the pictures of stars around the sky coverage of zenith, then the stars on the pictures are matched with the given star catalogue. We can obtain the star’s coordinate through the matching process. The plumb line (zenith point) can be resolved through the stars’ coordinates. We may
calculate the long latitude of astronomy of local station after obtaining the celestial sphere coordinate of zenith point if the UT1 is known. The deflection of the vertical can be calculated when we compare the long latitude of astronomy with the longitude and latitude obtained with GPS. The accuracy by this method obtaining the deflection of the vertical is the highest one in all measuring methods. On the other side, we can obtain the UT1 if the long latitude of astronomy is known.

With the observing ways similar to the traditional PZT, DZT takes pictures at 0 degree position first, and then turns around to the 180 degree position to take pictures. DZT turns around between 0 degree and 180 degree positions to take pictures during the set time in this way. The fixed point in the two pictures taken at 0 degree place and 180 degree place respectively is the projection point of the axis of DZT on the pictures. In last, to calculate the position of the zenith point must introduce the correction of electro-inclinometer.

The most noteworthy difference while observing between DZT and other optical telescopes is the turn-around repeatedly between 0 degree and 180 degree positions. Correspondingly, the paired pictures are processed ever time when data processing. The advantage of turn-around repeatedly between 0 degree and 180 degree positions is as follows:

- To determine the position of zenith point on the picture;
- To eliminate the change of projection point of plumb line on the picture due to the rotation of rotation platform.

DZT takes the photos of stars near the zenith point by turning-around between 0 degree and 180 degree, then we process the photos according to the star catalogue. After taking into account the correction of electro-inclinometer, we obtain the celestial coordinates of zenith point \((\alpha, \delta)\). In general, the long latitude of astronomy of the local station \((\Lambda, \Phi)\) is the given quantity, so \(GAST = \alpha - \Lambda\), here GAST is the Greenwich apparent sidereal time. Then GAST can be converted to the Earth Rotation Angle (ERA), \(ERA = GAST - E_0\). ERA is the angle between terrestrial intermediate origin and celestial intermediate origin. \(E_0\) is the equation of the origins, which represents the angular distance of the celestial intermediate origin from the Vernal Equinox. \(E_0\) contains the integral effects of the procession and nutation from the Earth rotation. ERA may be converted to the Julian Day:

\[
JD_{UT} = \frac{ERA - 0.7790572732 \times 40}{1.0027378119135448} + 24515450,
\]

here, \(JD_{UT}\) is the Julian Day corresponding to UT1. So the Universal Time can be obtained:

\[
\Delta UT = \frac{JD_{UT} - JD_{UTC}}{86400},
\]

here, \(JD_{UTC}\) is the Julian Day corresponding to UTC.

### 2.3. Observing Features of DZT

Generally, DZT has the observing features when comparing with other optical telescopes as follows:

1. No the tracking mode. DZT do not have to track the stars when observing, it only take photos of the stars entering the field of view.

2. Not necessary to compile the observational program before observing, so DZT can take photos at any time so long as the weather conditions permit. This observing mode improves the observing efficiency.

3. Adopting the turn-around observing mode between 0 degree and 180 degree positions.
(4) DZT uses the electro-inclinometer to replace the quicksilver horizon [8] to maintain the level of equipment, which avoids the environmental pollution.

(5) Every exposure of DZT contains several hundred stars in a picture, but the traditional exposure of PZT can only contain one star in a picture.

(6) DZT uses CCD as the image terminal, which makes the observing, data collection, and data processing realize the automation.

(7) DZT can be controlled remotely by the internet, which reduce the cost of operation.

2.4. Process of Observing

After DZT is transported to the observatory, the first step of the installation is to adjust the mounting direction, and to make the direction of one edge of CCD align with the East-West direction. We can carry on a long exposure, e.g. 10 seconds, and then judge the depth of parallelism between the edge of CCD and the east-west direction according to the lengthen star image as shown in figure 2. For the fixed station, the direction of CCD is only required to determine in the first time.

![Figure 2. Star image with 10 seconds exposure.](image)

After the mounting direction of DZT is determined, the tune-up of horizontality of DZT is necessary. In general, DZT is carried on initial horizontalization by the bubble level while DZT is installing. After initial horizontalization, the electron-inclinometer will automate DZT level, the levelness is in 2 arcsecond.

DZT can carry on the observations of stars after the mounting and horizontalization. The detailed observing procedure is as follows:

(1) Adjust the focal distance of DZT. The variation of temperature will change the length of the DZT tube, which will make CCD deviate the focus plane and result in the image indistinctness. So it is necessary to do an exposure of 0.5 second before the formal observing, and then decide whether to adjust the focus by checking the image quality.

(2) Open the control software, set up the observing time. The observing system will make the DZT automate horizontalization at the beginning time set up in advance. DZT will turn around between 0 degree and 180 degree several times. The horizontalization system will give the corrections of level according to the measure of electron-inclinometer. After the precise horizontalization, DZT will carry on the formal observing of the stars, and store the data on the computer hard disk.

3. System Composing of DZT Net

Now DZT net includes three observatories and one data processing center. The data processing center is located in Xi’an, the headquarters of NTSC. Three observatories are located in LuoNan, DeLingHa, and LiJiang. Scientific research personnel controls 3 observatories in the data processing center through internet. The device configurations and design structures are identical. Every observatory is consist of dome, DZT, UPS back-up power, server, network switch, video monitor, computer, PDU.
power management system, etc. Figure 3 shows the sketch map from the data processing center to the observatory.

![Figure 3. DZT net.](image)

4. Inclusion
NTSC has constructed the DZT net, the DZT net has three observatories. Now DZT net is the unique optical observing net dedicated to UT1 measuring. This DZT net can also monitor the variation of deflection of the vertical except for carrying on measuring UT1. Monitoring of deflection of the vertical can provide the important data for the geodesy.

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