The step tracking system of LHAASO-WFCTA

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Abstract: Based on fully understanding and deeply analyzing the current status of the detecting methods, the step tracking system of Wild Field Cherenkov Telescope (WFCT) has been designed. It is the combination of manufacturing and detecting method to achieve the accurate observation. The telescope rotation precision achieves 0.2°,and through calibration by using stars, the accuracy class is improved to 0.01°.

Keywords: LHAASO, WFCTA, observation accuracy, testing equipment

1 Introduction

Aiming at wide field of view survey for sources of gamma rays at energies above 100 GeV, the search for cosmic ray origins among those gamma ray sources at energies above 30 TeV and energy spectrum measurements for individual cosmic ray species from 30 TeV to 10 PeV, a Large High Altitude Air Shower Observatory (LHAASO) project with a complex array of many types of detectors is proposed. As one of the components of LHAASO project, two wide field of view telescope (WFCT) prototypes were installed at YangBaJing Cosmic Ray Observatory in 2007 and have been successfully running since Aug. 2008. Millions of cosmic ray events have been collected[1].

In order to explore the potential possibilities as imagining cherenkov telescope and deeply understanding detection, analysis method, one of the WFCT telescopes is updated to a step tracking system. The tracking system is used to track the γ ray sources to study the energy spectrum of the sources. In addition, with the large field of view, the telescope can be used to study the extent sources.

In this paper, the details of this tracking system is introduced, on the basis of manufacture precision a further calibration of the point accuracy by using the star light is employed.

2 Step-tracking

A tracking system is designed to track γ ray sources. Due to the large field of view (FOV) ($14° \times 16°$) of the telescope, it takes a point like γ ray source about 50-60 minutes to pass though the FOV of the telescope depending on the declination of the sources, so a step by step tracking mode is chosen.

The interval of the telescope has to change its pointing based on two factors. One is the accuracy of the pointing of the telescope which can be calibrated by bright stars, the other is the uniform observation to the neighborhood of the target, which is used to estimate the background of the target. If the telescope changes its pointing in a short time, the uniformity can be kept very well, however, the calibration of the pointing of the telescope becomes very difficult due to the lack of the use of bright stars.

For example, when the telescope aims to observe the Crab Nebula, the pointing of the telescope is modified every 50 minutes based on requirements of the pointing accuracy and the uniformity of observation. Figure 1 shows the trace of Crab Nebula with the FOV of the telescope in the local coordinates. When Crab is on the positions shown by the red dots, the pointing of the telescope is changed in order to keep the sources always within the FOV of the telescope. And figure 2 shows the uniformity of the observation to the neighborhood of the Crab Nebula. The black area in figure 2 indicates the area with uniform observation. In order to avoid the lost of the uniform area, the pointing accuracy should be high.

3 Mechanical structure

According to the observation requirements, the following three items have to be satisfied with the new step tracking system: (1) a two dimensional rotation system is implemented, and the valid rotation range is [0°-90°] in the vertical direction and [-270°, 270°] in the horizontal direction; (2) the rotation speed of the tracking system can be

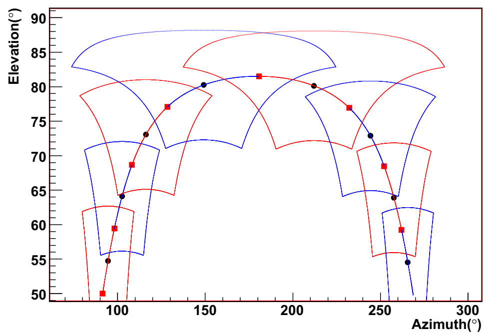

Figure 1: The trace of Crab Nebula in the local coordinates with the FOV of the telescope. The red and blue boxes indicate the FOV of the telescope in the local coordinates. The black dots show the center of the FOV of the telescope (the pointing of the telescope). The red dots indicate the pointing of the telescope is changed.

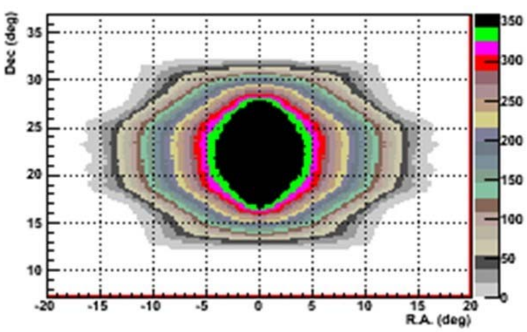

Figure 2: The uniformity of the observation to the neighborhood of the Crab Nebula.

adjusted; (3) in the point of view mechanical system, the rotation precision of the tracking system is less than 0.2°.

The step tracking system is composed of 6 sub-system: base, structure, azimuth-rotation device, zenith-rotation device, hydraulic and electrical system, as shown in figure 3.

The optical device is the most important part of this equipment. It consists of a camera composed of 16×16 PMT arrays, a 4.7 m^2 spherical mirror, hydraulic door and relevant electronics systems. The whole optical device is installed in a shipping container. The weight is around 3 tons.

The optical tube is fixed in the closed frame which is connected by the bolts. Side supports ensure the box rotate reposefully at the zenith, the distortion of all the structures is less than 0.2 mm under the normal operation.

The process of azimuth rotate should be smooth and steady, and the crawl of Hydraulic pressure motor is very serious at low speed, so it would affect the result of testing if we use the motor. The azimuth rotary device is structure with

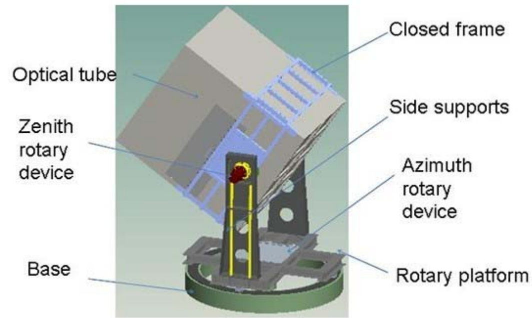

Figure 3: The mechanical structure of detector

Rotary gear reducer and the Turntable Bearing, which suits for the equipment.

Optical tube is set on the rotary platform which is made of profiled bar. The structure cannot be destroyed in Class 12 wind and can normally run in Class 7 wind, so the accuracy of observational data is ensured.

The base is made of reinforced concrete, which contains two parts: the middle support base and the round guide track. The middle support endures all weight of the equipments. The round guide track can keep the equipment from leaning and temporarily bear the force of over loading.

The rotary actuator can rotate the testing box at the zenith, which is composite actuator with gear-wheel and rack. It may modify the hydraulic energy to transmit mechanical energy. The movement of reciprocating piston and rack drives gear output torque and corner.

For Wild Field Cherenkov Telescope, the hydraulic station is the power system and there is overload protection for motor in the electric system. All action are controlled and checked by computer, so it can run automatically in the normal state even without supervision.

As detection system, the minimum angle should be ”arc second”, so the Absolute Encoder is adopted. After debugging and testing the equipment, the rotational errors are less than 0.2° during zenith rotary and azimuth rotary, meeting the design requirements.

4 Pointing calibration by using bright stars

As mentioned in section 2, the pointing accuracy of the tracking system can be achieved within 0.2°. In order to improve the pointing accuracy further, bright UV stars are used to calibrate the pointing of the telescope. In addition, the bight stars can also be used to study the systematics of the tracking system.

4.1 Star light

The telescope is designed to observe the Cherenkov light (300nm-600nm) emitted by the secondary charge particles in the EAS showers. For each air shower event, the signal of Cherenkov light can only lasts a few of nanoseconds, while the trigger window lasts $18\mu s$, thus in most of the trigger window, the telescope records the contribution of night sky background (NSB).

The NSB contains two components, one is the diffuse lamplight from the town of Yangbajing , the other one with well known directions and stable fluxes is from the bright stars appearing in the FOV of the telescopes. The two components are added to the signal of Cherenkov light and is recorded by the telescope. In order to avoid the contribution of the Cherenkov signal, only the average signal in the final 2μs of the trigger window is used to estimate the relative strength of the NSB. In order to reduce the fluctuations of NSB, the value of the recorded NSB is averaged every 10 minutes. The NSB recorded by one PMT in an observation night is shown in figure 4. The peaks in the figure 4 are caused by the bright stars. The peak amplitude of a star light in a PMT depends on its UV magnitude and its projected position on the camera plane. The peaks means a star appeared in the FOV of the telescope again for each change of the telescope. In order to avoid the effect of the diffuse NSB with value around 35 FADC counts, it is subtracted as background.

The positions and fluxes of the bright stars can be obtained from star catalogs. In out analysis, the TD1 catalog is used, which has four different wavelength bands, 1565, 1965, 2365 and 2740 $\mathring{A}$, respectively[2]. The WFCT telescopes are sensitive in the near UV band , so the last wavelength band with flux above $1 \times 10^{-11} erg/cm^2/s$ of TD1 is used.

4.2 Pointing of the telescope

According to the pointing given by the tracking system, the time when the brightest star appears in the FOV of the telescope can be found through the brightest PMT. Although the gain and uniform are calibrated by a led installed on the mirror[1]. ,however, due to the large size of the PMT ($1^\circ \times 1^\circ$), the positions of the PMT can not indicate the positions of the brightest star on the camera accurately. So the weighted center (x_0, y_0) by the FADC counts of the PMT and its neighbors within 2° is considered as the position of the star on the camera. According to the position, the trace of the brightest star on the camera can be obtained shown in figure 5. In figure 5, in order to show the relative positions between the PMTs and the traces of stars obtained by the PMTs, the 256 PMTs are plotted by the red hexagons.

In order to get pointing of the telescope, the trace of the brightest star is fitted by a linear function. When the star is in the middle of the camera in the horizonal direction, it has the same azimuth angle with that of the telescope, while the elevation angle of the star is equal to the elevation of the telescope plus the angular distance between the position of the star and the center of the camera.

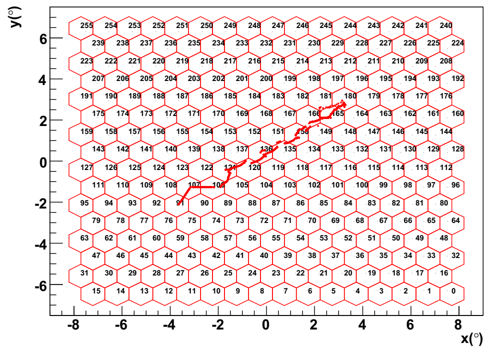

Figure 5: The trace of the brightest star on the camera. The red hexagons indicate the PMTs. The x and y axes indicate the coordinate of the focus plane in degree.

The spot size formed by the parallel light is from 0.17° to 0.28° from the center of the camera to the edge of it[3]. So in order to get rid of the effects of the nearby stars, the orphan stars which have no surrounding stars within 2° are used to correct the pointing direction of the telescope obtained by the brightest stars, furthermore. In the neighborhood of Crab, there is about eight orphan stars.

The traces of the orphan stars on the camera can be obtained through the pointing of the telescope by the brightest stars. So the positions observed by the telescope of the orphan stars in the horizonal coordinates are obtained. The average differences between observed positions and the real one are reported back to the pointing direction of the telescope and the process is iterated. The difference between the observed one and the one of the star positions in the horizonal coordinates is defined as the accuracy of the pointing direction which are shown in figure 6. The top panel shows the accuracy in the azimuth direction, while the bottom one shows the accuracy in the elevation direction. The RMSs of the distributions are about 0.20° and 0.17°, respectively. Considering the number of the orphan star used, the accuracy of the pointing obtained by the method is better than 0.01°. The pointing of the telescope for each rotation can be calibrated by the method.

With the accuracy of the calibration better than 0.01°, the systematics of the pointing of the tracking system can be studied. For each rotation, the pointings of the telescope are recorded by the tracking system, and the differences between the pointings obtained by the bright stars and the ones from tracking system can be considered as the systematics of the tracking system. One night data is used to study the systematics. The differences for each rotation are shown in figure 7.

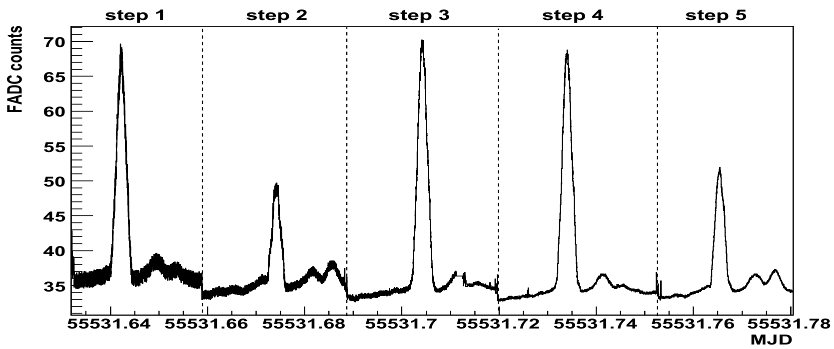

Figure 4: A typical recorded by one PMT in an observation night.

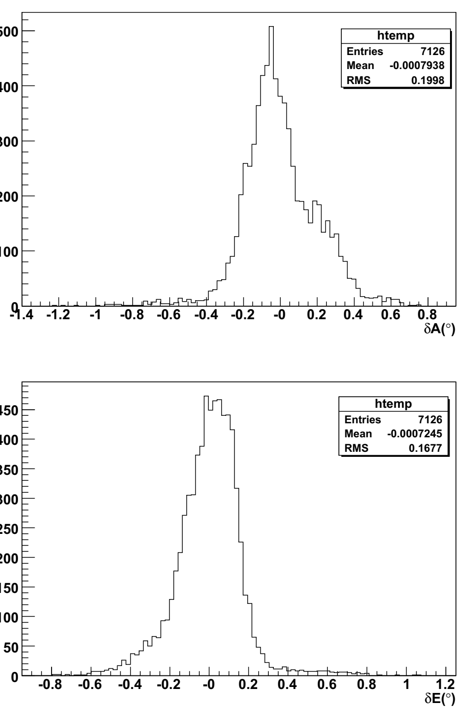

Figure 6: The accuracy of the pointing of the telescope. The upper plot shows the accuracy in the azimuth direction, while the bottom one shows the accuracy in the elevation direction.

5 Conclusion

The two WFCTA telescopes have been running for 4 years smoothly. Recently, the mechanical structure of one of the telescopes has been updated to track the γ ray sources. The accuracy of the pointing of the tracking system is within $0.2°$. In order to improve the accuracy of the pointing of the telescope, a method using bright stars to calibrate the pointing of the telescope is used. After calibration, the accuracy of the telescope is better than $0.01°$ both in azimuth and elevation direction.

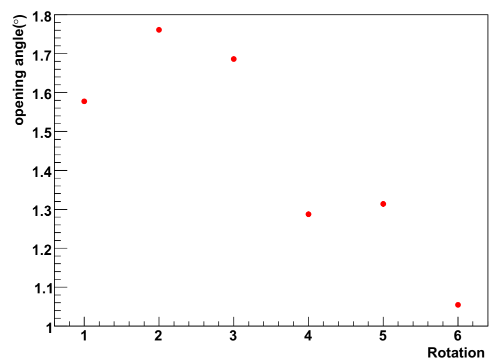

Figure 7: The systematics of the tracking system. The space angle between the pointing of obtained by the stars and the one given by the tracking system.

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