Application of the nitrogen laser calibration system in LHAASO-WFCTA

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The nitrogen laser calibration system for the Wide Field of View Cherenkov Telescope Array (WFCTA) is one of the most important components of the Large High Altitude Air Shower Observatory (LHAASO). This calibration system is composed of three parts, including a high-precision 3D lifting and rotating platform (HiRoP), a nitrogen laser and the wide field of view Cherenkov telescope prototypes. The accuracy of the HiRoP is of great importance for the precise calibration of WFCTA since it controls the laser beam's pointing direction. A home-made HiRoP was introduced and the measurements implies that the angular and lifting accuracies of HiRoP are better than 0.003° and 0.075 mm, respectively. Furthermore, the pulse energy stability of the nitrogen laser beam is another remarkably important factor. The nitrogen laser system with a wavelength of 337.1 nm located in a high-precision temperature and humidity's controlling container, resulting in a pulse energy fluctuation less than 3 percent. Besides, the method of a standard zero verification is employed to improve the long-term accuracy of the beam pointing direction.

1. Introduction

The Wide Field-of-view Cherenkov Telescope Array (WFCTA) is one of three detector arrays of Large High Altitude Air Shower Observatory (LHAASO) [1]. WFCTA is an array of Cherenkov fluorescence telescopes, where a movable design idea is adopted. The different array configurations are used for Cherenkov observational mode and fluorescence observational mode to realize the different scientific objects[2]. It aims to measure the spectrum of cosmic rays from 10 TeV to 1 EeV by calculating the number of photons detected. Therefore, the absolute calibration of the number of photons received by WFCTA is the key to obtain the accurate energy of the original cosmic rays.

The nitrogen laser calibration system is widely used in the detectors with Cherenkov/fluorescence observational mode. In the calibration process of LHAASO-WFCTA, the accurate pointing of the laser beam in the all sky is accomplished by the rotating of HiRoP. The accuracy of each parameter of HiRoP is critical for that. Pierre Auger Observatory's fluorescence telescope detector array also uses a similar laser calibration system which provided the absolute accuracy of pointing is less than 0.2°, and the relative accuracy is maintained within 1/80°[3,4].

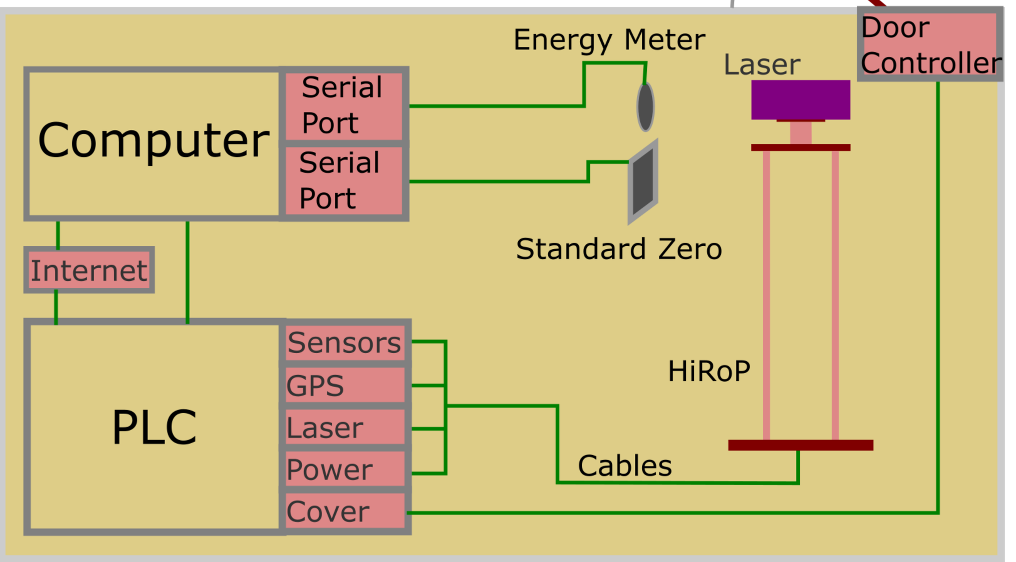


Figure 1: The schematic of the nitrogen laser calibration system.

In this presentation, the angular and the lifting repeatabilities of HiRoP are better than 0.003° and 0.075 mm, respectively. And the method of standard zero point is employed to assure the long-time accuracy of the beam pointing direction. The application of thermotank is introduced to improve the energy stability of emitted laser beam to less than 3%.

2. The standard zero point

Shadow-Tip Method is employed to find the north direction, and the horizontal direction with gradienter, which defined as standard zero point. However, long time running may induce some errors of the direction. Special equipment is set up to monitor the standard zero point(Fig. 2). If the laser spot changes from O point to A point, the trigonometric function relationship can convert the change of the spot displacement (X pixels) to the angle change of rotation, which can be expressed as: $\Delta\theta = \gamma \Delta x / L$, where γ is the factor that convert pixel to actual distance.

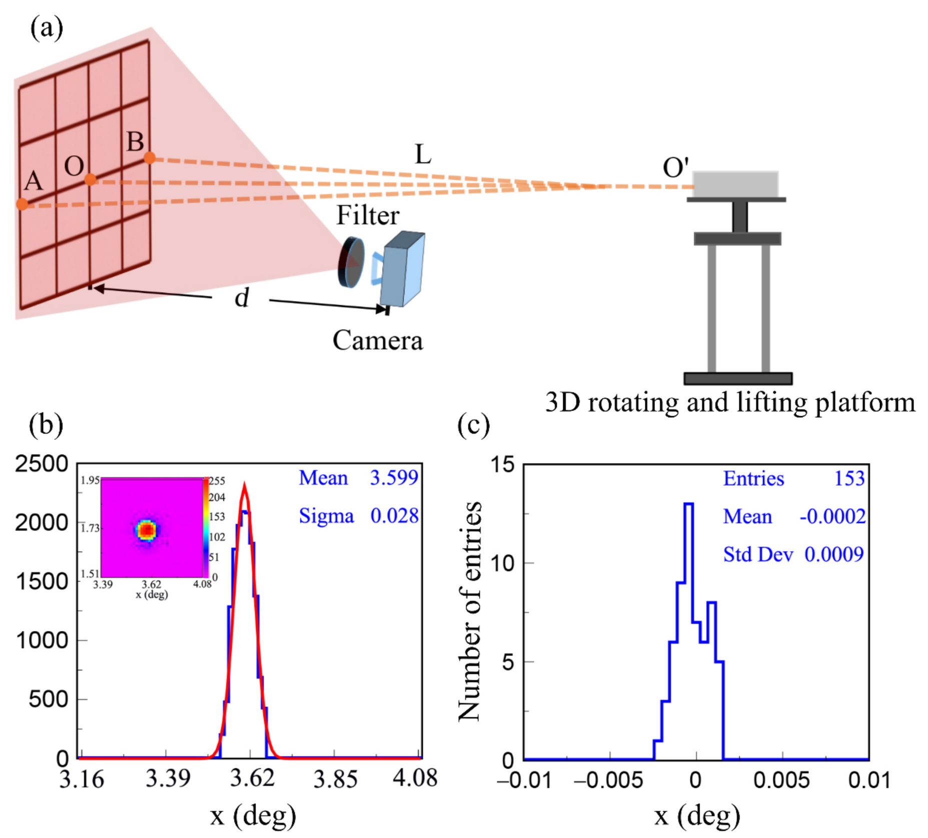
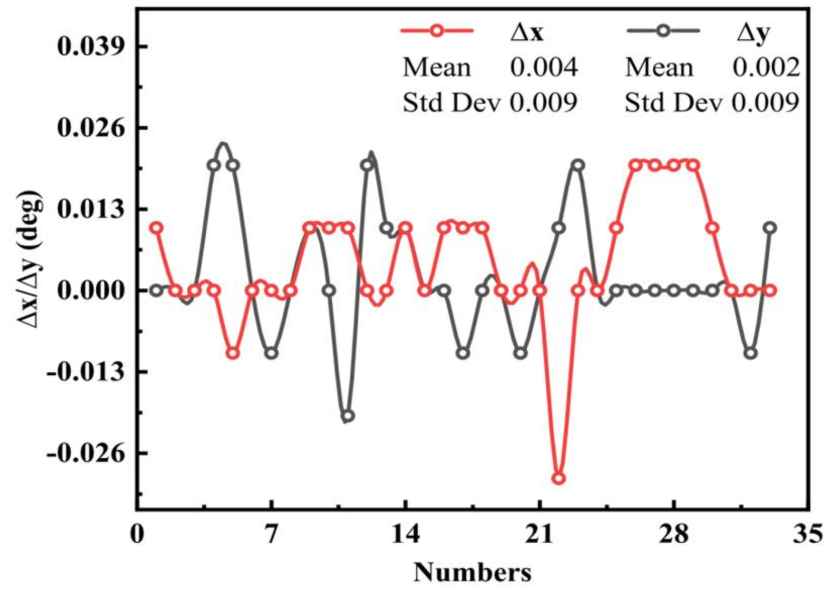


Figure 2: The principle of digital image processing method. (a) Schematic diagram of experimental system construction; (b) The image of the light spot and the projected intensity distribution of the spot on the horizontal axis (blue) and Gaussian fitting curve (red); (c) The distribution of laser beam position projected in the horizontal direction.



After 33 days normal running of the laser calibration, the data implies that our system is quite stable, as shown in Figure \ref{standardzero}. In the most days, the errors are less than 0.01°, which is the resolution of 0.01 degree monitored by PLC. SO Those days can be considered as normal ones. If not, further action is taken to regulate the standard zero point.

Figure 3. The standard zero position monitoring in horizontal direction and pitch direction with 33 days.

3. HiRoP

The schematic diagram of measurement principle of HiRoP is the same as the method of standard zero point in Fig. 2. The PLC controls the rotation of HiRoP, which is set to a specific angle, named $\Delta\theta$. The laser beam will reach a new position, and the difference between the two positions is the actual rotation angle $\Delta\varphi$ of the HiRoP obtained from the method.The HiRoP rotates forward with a certain step, which then stop and run in the opposite direction without doing any operation. As shown in Fig.4, the spot position is linearly fitted. Where P0 is the y-intercept of the fitting straight line, and P1 is the fitted slope value.The closer to 1 the slope value approaches, the better the consistency between the setting value of PLC and the real rotation value measured by the method. The blue dots are the fitting results of the forward data, and the red dots are the fitting results of the reverse data. The difference between the y-intercept values of the two fitting straight lines is rotational error.

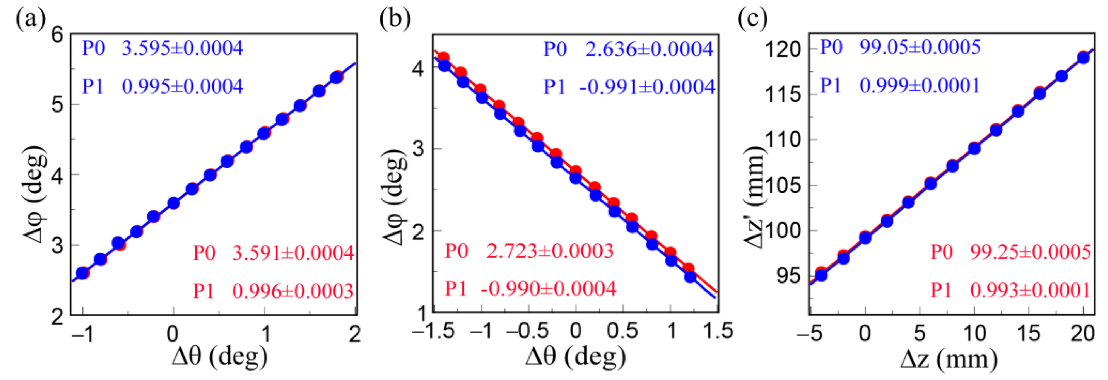
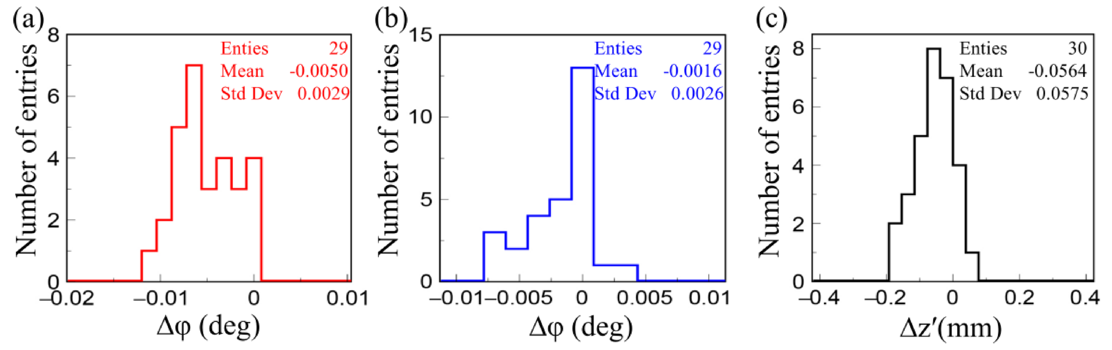


Figure 4: The back lash of the no-load 3D rotating and lifting platform.

The back lash of the azimuth direction is 0.004° degrees in Fig.4(a). The back lash of pitch direction is 0.087° in Fig.4(b). The back lash of lifting direction is better than 0.2 mm in steps of 2 mm, as shown in Fig.4(c). The slopes of the three fitting straight lines are 0.99, 0.99, 0.98, respectively.



The repeatability of horizontal direction is maintained within 0.003° in Fig. 5(a). The repeatability of pitch direction is less than 0.003° in Fig. 5(b).The repeatability of lifting direction is within 0.058 mm in Fig. 5(c)

Figure 5: Repeatability and positional accuracy of non-load HiRoP.

4. The performance of the nitrogen laser

NL100 nitrogen molecular laser is used in the calibration system as laser source. The wavelength of the laser is 337.1 nm, and the pulse energy is 170 uJ. The environment of LHAASO located at Haizi Mountain, Daocheng County with an altitude up to 4410 m, is harsh that the temperature often changes from 10 degree to -20 degree during one night. Special protections are employed to guarantee its normal working. As shown in Fig. 6, thermotank is designed to keep the laser stay in the stable environment with a constant temperature. The thermotank can not only control the temperature, but also prevent the dust or the rain outside.

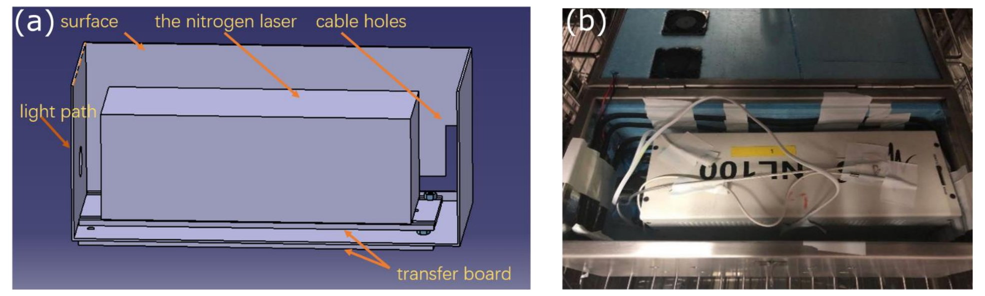


Figure 6: The nitrogen laser and thermotank. (a)the design of thermotank; (b)the diagram of the laser and thermotank.

The energy of the nitrogen laser is directly related to the accuracy of WFCTA calibration. When the laser stores in the thermotank, its energy stays more stable as shown in Fig. 7. Removing the first hundreds of second data, the energy stability is about 3% over 11 hours. During our observation time, the energy of the laser is recorded at the beginning after warming up and at the end of the observation for half an hour. The average energy of the two period predicts the laser energy during the none-measure time.

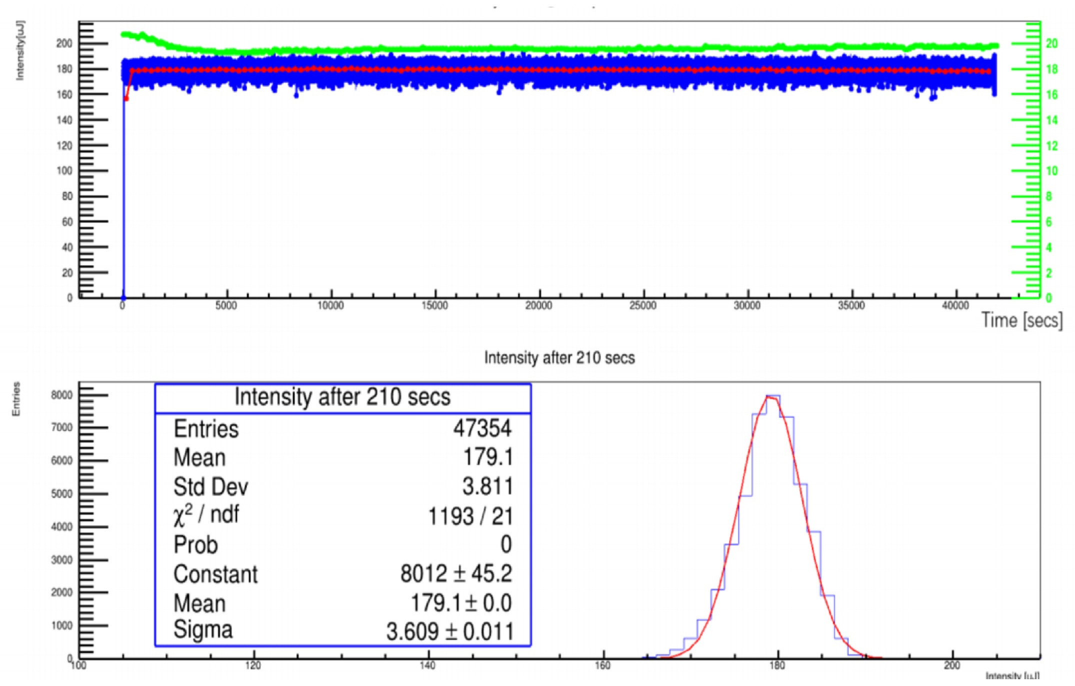


Figure 7: The energy of the nitrogen laser.Top panel: the blue line-dots is the nitrogen energy pulse by pulse, the red line-dots is the average value of one minutes, the green line-dots is the temperature in the thermotank. Bottom panel: the statistical energy data.

Discussion

The calibration system is a complicated system. In this poster, some dominant components of the nitrogen laser calibration system are discussed. The high precision of HiRoP is the fundamental of the pointing accuracy of the laser. The application of the standard zero point assures the long time running. Special protection of the laser provides the energy stability of the laser. All of them provide the final performance of the nitrogen laser calibration system.

Reference

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