ICRC2017
35th International Cosmic Ray Conference

TAIGA

Software design for the TAIGA-IACT telescope pointing and control system

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Telescope Hardware

Reflector
- Davis-Cotton design
- 34 segments
- segment diameter 60 cm
- reflecting surface ~10 m^2

Cherenkov camera
- 547 PMTs
- each PMT in Winston cone
- FoV 10º x 10º
- angular res. 0.36º per pixel
- 8 LEDs around the perimeter

CCD-camera
- Prosilica GC1380
- Computar 16mm Camera Lense 1:1.4 2/3" 04K
- 1360 x 1024 pixels
- 12-bit ADC
- FoV 30.8ºx23.4º
- angular res. 0.023º per pixel
- Exposure time 1 μs – 1 min
- Controlled over Ethernet

Drive system
- PhyTron stepper motors
- 2 gearboxes – gear ratio 2000
- Axis res. 0.001º per step
- Micro step mode up to 1/512
- Controlled over Ethernet
- 2 limit switches on each axis

Introduction

The First TAIGA-IACT Telescope installed in Tunka valley. Picture taken in April 2017.

The **TAIGA** observatory (**T**unka **A**dvanced **I**nstrument for cosmic ray physics and **G**amma **A**stronomy) is located in Tunka valley at a distance of 50 km from Lake Baikal. The TAIGA observatory is a complex system of ground-based extensive air showers detectors. It consists of various types of detectors, including wide-angle detectors of Cerenkov radiation, radio-antennas, detectors of electrons and muons of EAS. In December 2016, **the First Image Atmospheric Cherenkov Telescope TAIGA-IACT** was installed in the Tunka valley. On the 2016-2017 data tacking season only 6 of the 34 reflector segments is installed on the telescope.

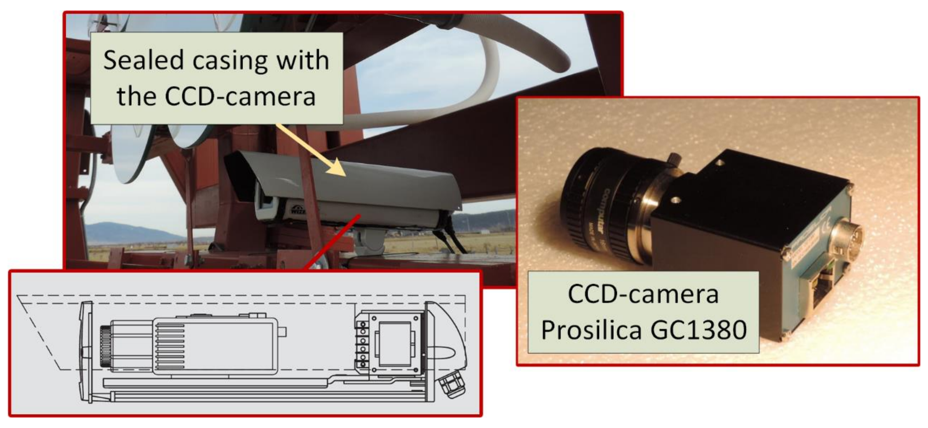
Software used for development

The following software is used for telescope pointing and control system development:
- **EPICS** – Experimental Physics and Industrial Control System
- **SOFA** – Standards of Fundamental Astronomy
- **Astrometry.net** software

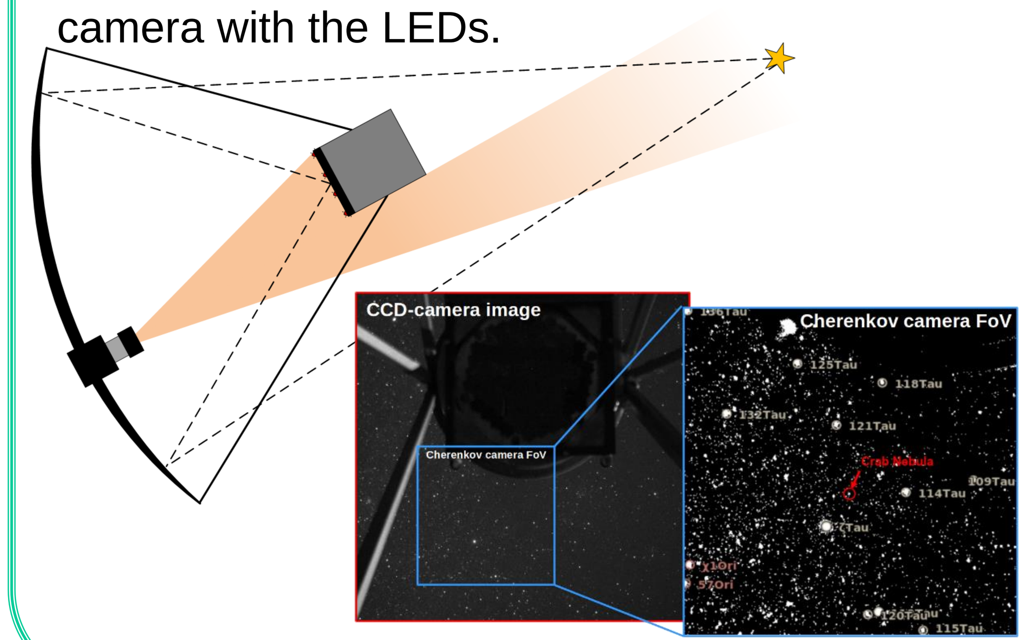
As framework for development of the telescope control system a set of software tools **EPICS** is used. **FITS file format** is used for saving CCD-images. To calculate the observed source coordinates the software **SOFA** is used. **EPICS Qt Framework** is used for graphical user interface development. For astrometric calibration by the CCD-camera images **Astrometry.net** software is used.

CCD-Camera

To perform the calibration measurements and determine the accurate position of the telescope the CCD-camera Prosilica GC1380 was installed on a dish of the telescope near the mirrors. It is placed in the sealed casing WizeBox SVS32P with protection mark IP66 to maintain operation conditions.



The CCD-camera was installed in such a way that it's position allows us capturing on the one image the observed source and the telescope camera with the LEDs.



CCD-camera image processing

To accurately determine the direction of the telescope in celestial coordinates using the CCD-camera images a number of calculations should be performed.

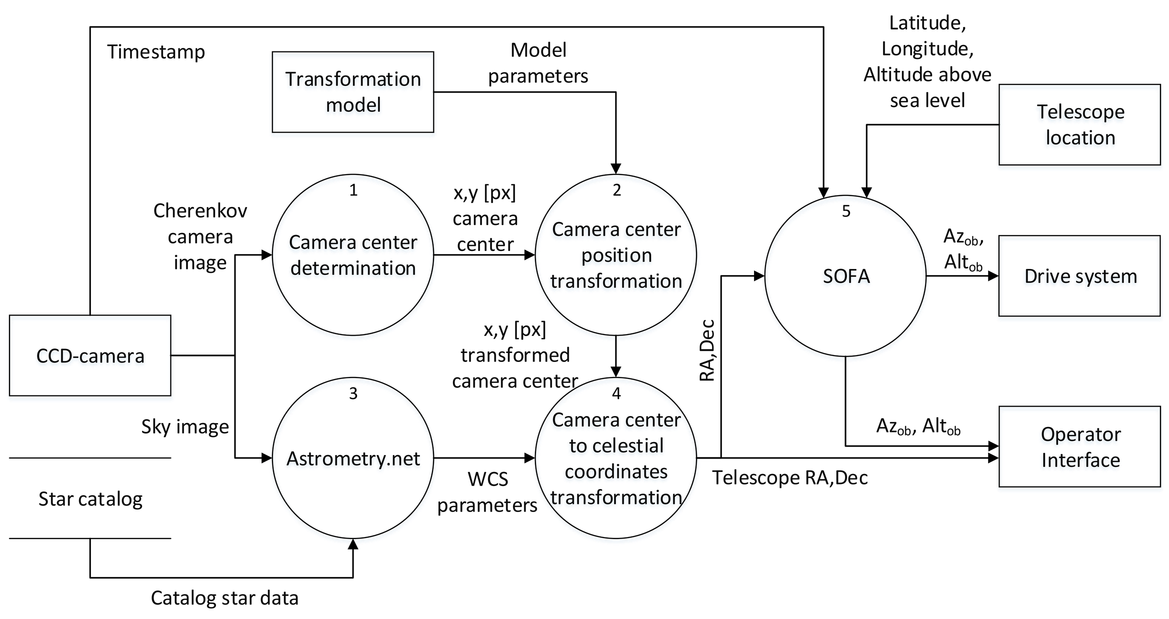
1. To determine the position of the Cherenkov camera center eight LEDs are used, each of which is equidistant from the camera center. The position of the LEDs is estimated as the center of gravity of their light distribution taking into calculation the pixels exceeding the established threshold above the background.

2. To mapping the obtained positions of the Cherenkov camera to the celestial region of the image in the pixel coordinates a transformation is used, that parameters are determined experimentally.

3.World Coordinate System (WCS) transformation parameters can be determined through **astrometry.net** software and the index files based on the astronomical catalogue **Tycho-2**.

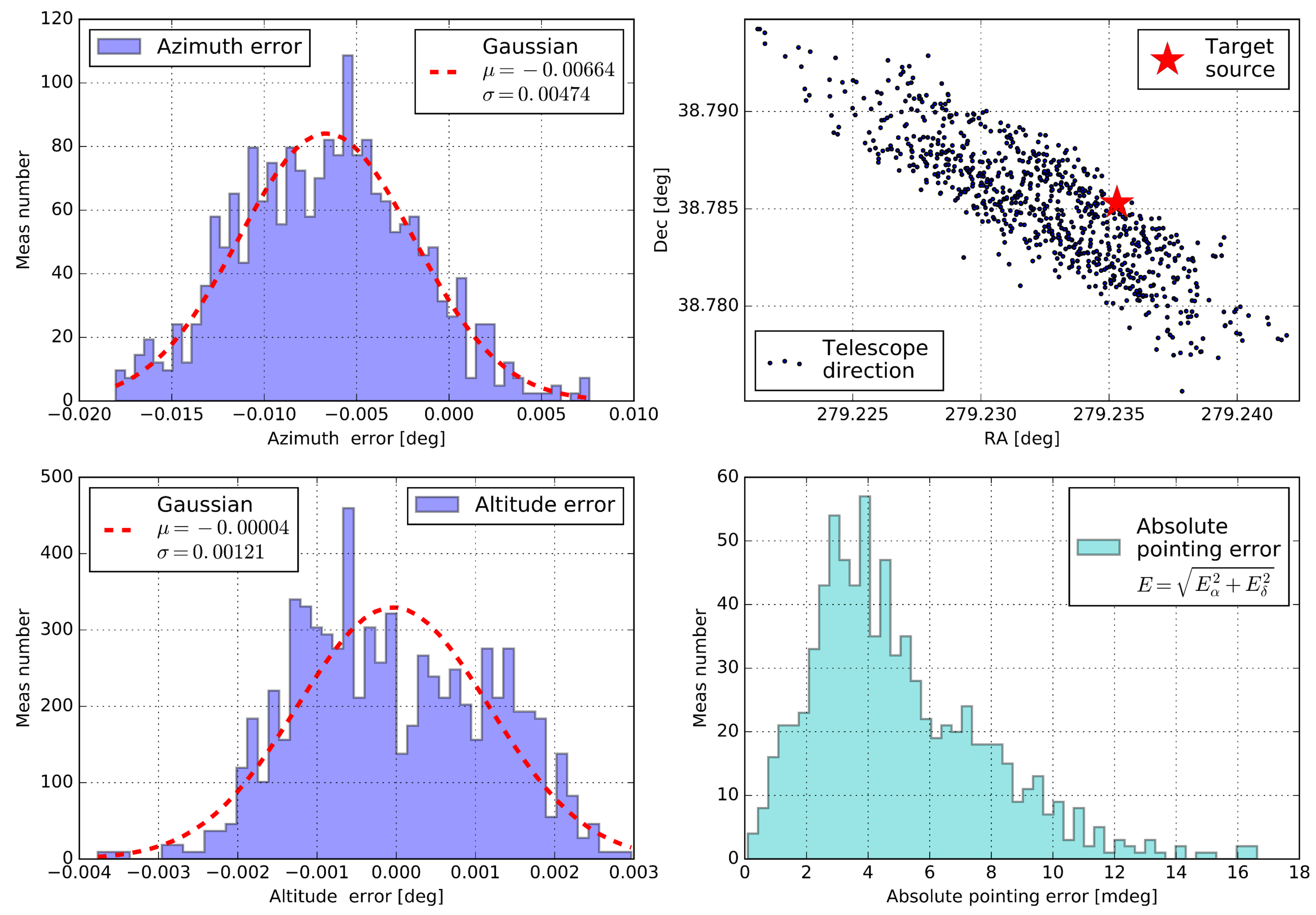
4.Using the transformed camera center position and WCS parameters the direction of the telescope in the RA-Dec coordinates is calculated.

5.The **SOFA** software libraries are used to determine the azimuth and altitude angles of the source.



Test operations in tracking mode with feedback from the CCD-camera

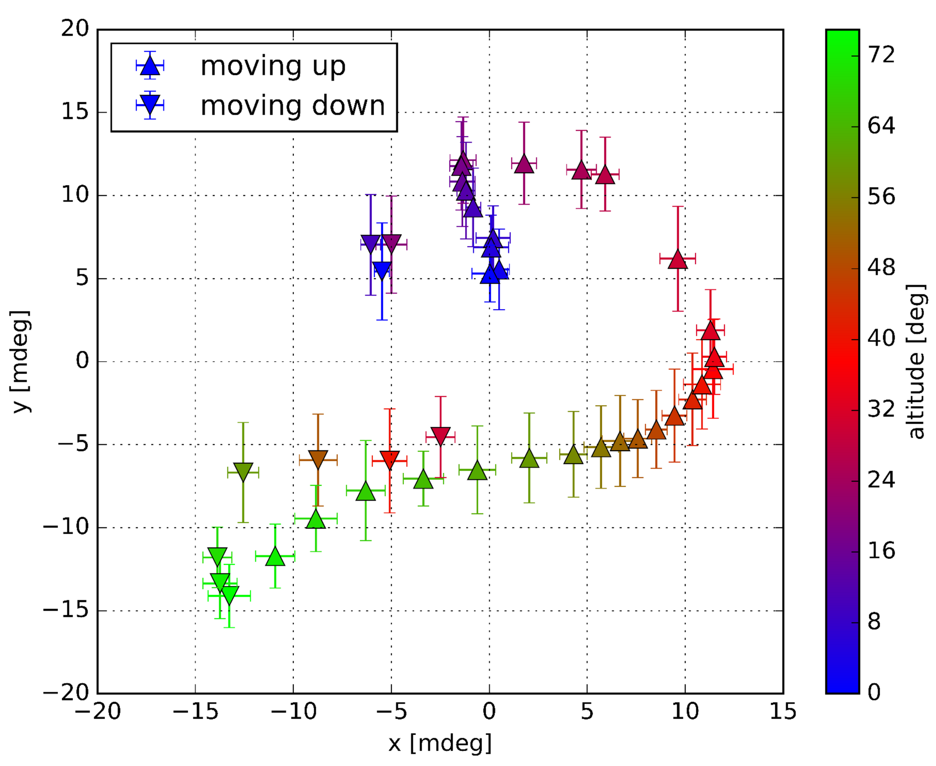
For the first test operations in the tracking mode in the absence of encoders on the axes feedback from the CCD-camera was implemented. These operations were conducted in clear, cloudless, windless nights. The resulting images from the CCD-camera were processed on-the-fly, that allowed to determine the azimuth and altitude position of the telescope. The position of the Cherenkov camera on images was used as a fixed value that means that the present result does not take into calculation the deformation of the construction. In this operation the Vega star was chosen as target source and for 13 minutes 807 CCD-camera images were obtained and processed.



A high deviation in telescope pointing is caused by a high dispersion of the azimuthal axis, which is evident from the distributions and the scatter plot. Nevertheless, from the pointing error distribution, it can be seen that the tracking accuracy was higher than the CCD-camera resolution. The main approach that will be used in the following operations is the use of feedback from the shaft encoders and a pointing model.

Deformation of the telescope construction

For studding of telescope construction deformation an experiment was made, that based on the position measurements of the Cherenkov camera on CCD-camera image. The telescope was raised up from a horizontal position to 72.5 degrees by altitude with 2.5 degree steps. After this it was moved down to a horizontal position. At each step a series of images were obtained. The telescope motion direction up and down is shown as triangles directed up and down respectively. Color indicates altitude of the camera. Maximum deviation from mean position does not exceed 0.02 degree.



Conclusion

The first Image Atmospheric Cherenkov Telescope TAIGA-IACT was installed in the Tunka valley in December 2016. The Prosilica GC1380 CCD-Camera is installed on the telescope for the pointing calibration and it's position allows capturing both the Cherenkov camera and the observed source. A set of software tools EPICS was used to development the control system for the drive system and the CCD-camera control. The image processing software allows to determine the telescope position on-the-fly. Tracking with feedback from the CCD-camera was implemented. After commissioning the first TAIFA-IACT telescope It will operate using the shaft encoders feedback and a pointing model. By 2019, it is planned to install 2 more IACT telescopes distributed at a distance of about 600 m from each other.

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