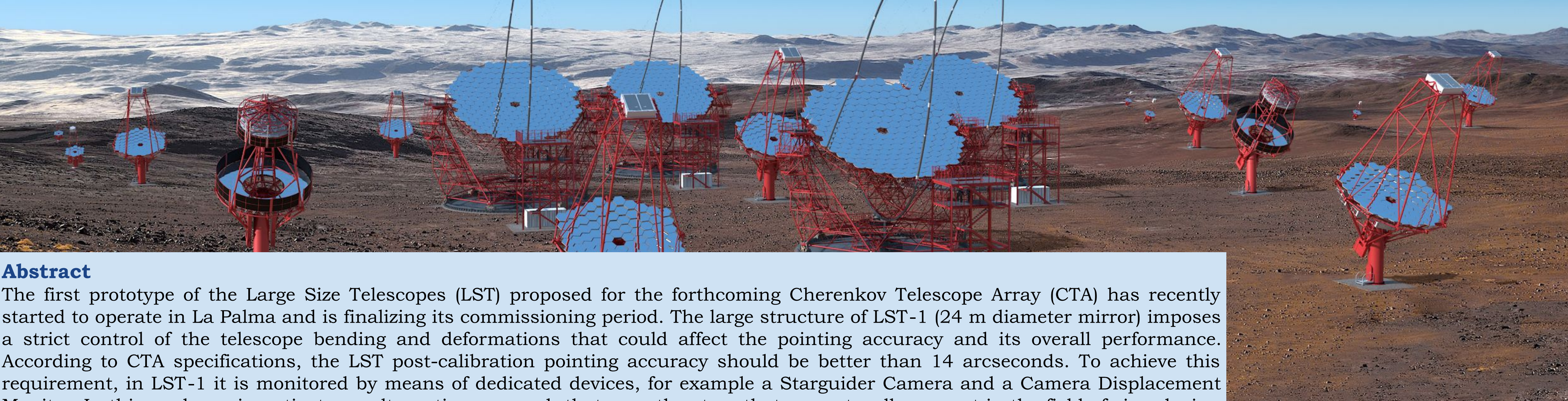


An alternative method to monitor the telescope pointing: application to LST-1

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Abstract

The first prototype of the Large Size Telescopes (LST) proposed for the forthcoming Cherenkov Telescope Array (CTA) has recently started to operate in La Palma and is finalizing its commissioning period. The large structure of LST-1 (24 m diameter mirror) imposes a strict control of the telescope bending and deformations that could affect the pointing accuracy and its overall performance. According to CTA specifications, the LST post-calibration pointing accuracy should be better than 14 arcseconds. To achieve this requirement, in LST-1 it is monitored by means of dedicated devices, for example a Starguider Camera and a Camera Displacement Monitor. In this work, we investigate an alternative approach that uses the stars that are naturally present in the field of view during observations. By cleaning from the Cherenkov showers the events registered by the camera, it is possible to obtain a picture of the sky at the pointed direction as it is reflected into the camera. The reconstructed positions of the stars in the field of view can be compared to their nominal expected position, providing a direct measurement of the mispointing of the telescope.

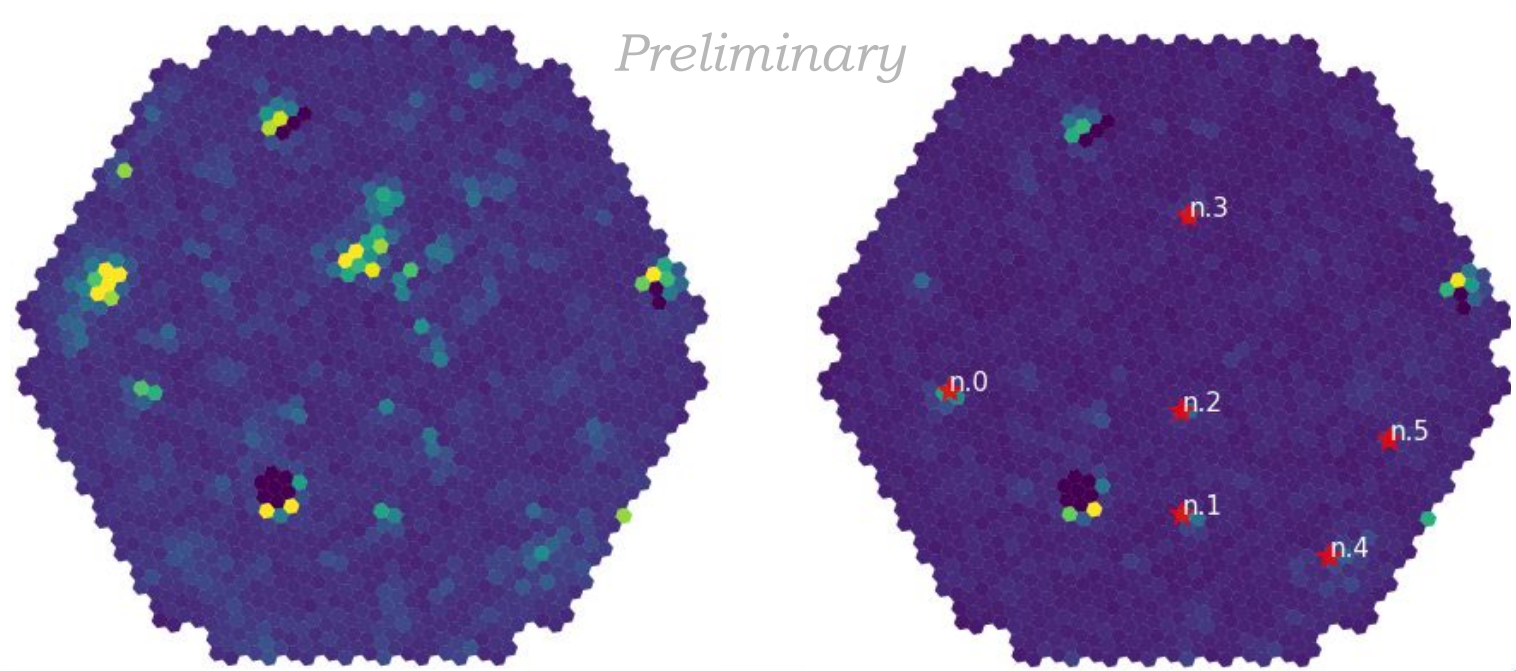
How it works

The method operates on all the **events** triggered by the telescope. In order to keep only the background, every event has to be properly filtered and the Cherenkov shower images have to be **cleaned** out (Fig.1).

In order to increase the signal to noise ratio, we consider the variance of the signal provided by the AC coupled PMTs to each camera pixel. After the cleaning, several events are stacked to form an **image** of the camera. The position of the stars in the camera frame is reconstructed by detecting the hotspot corresponding to the expected position of the star as converted from the catalogue to the camera frame.

Several checks are performed in order to verify if the star is properly detected, if it is sufficiently far from other nearby stars, or if there are PMTs in safe mode due to its high brightness.

Fig 1: Image obtained during LST-1 data taking before and after cleaning the events from the Cherenkov showers (left and right panel respectively). On the cleaned image, the position of the stars in the field of view as obtained by stars catalogs at the time of observations are reported.



Advantages of the method

- ❑ This method does not require any additional hardware or any specific technical observation time. It can be applied to **archival** data or as a **real-time** monitoring system during the normal data taking.
- ❑ By using all the events that are triggered by the telescope with a frequency of about ~8-10 kHz (high-frequency approach), the method allows us to monitor the pointing direction with a frequency potentially higher than the other conventional methods (Fig. 3).
- ❑ The analysis of real data potentially allows us also to monitor some optical performance of the telescope such as the Point Spread Function (PSF) and/or mirrors alignment.

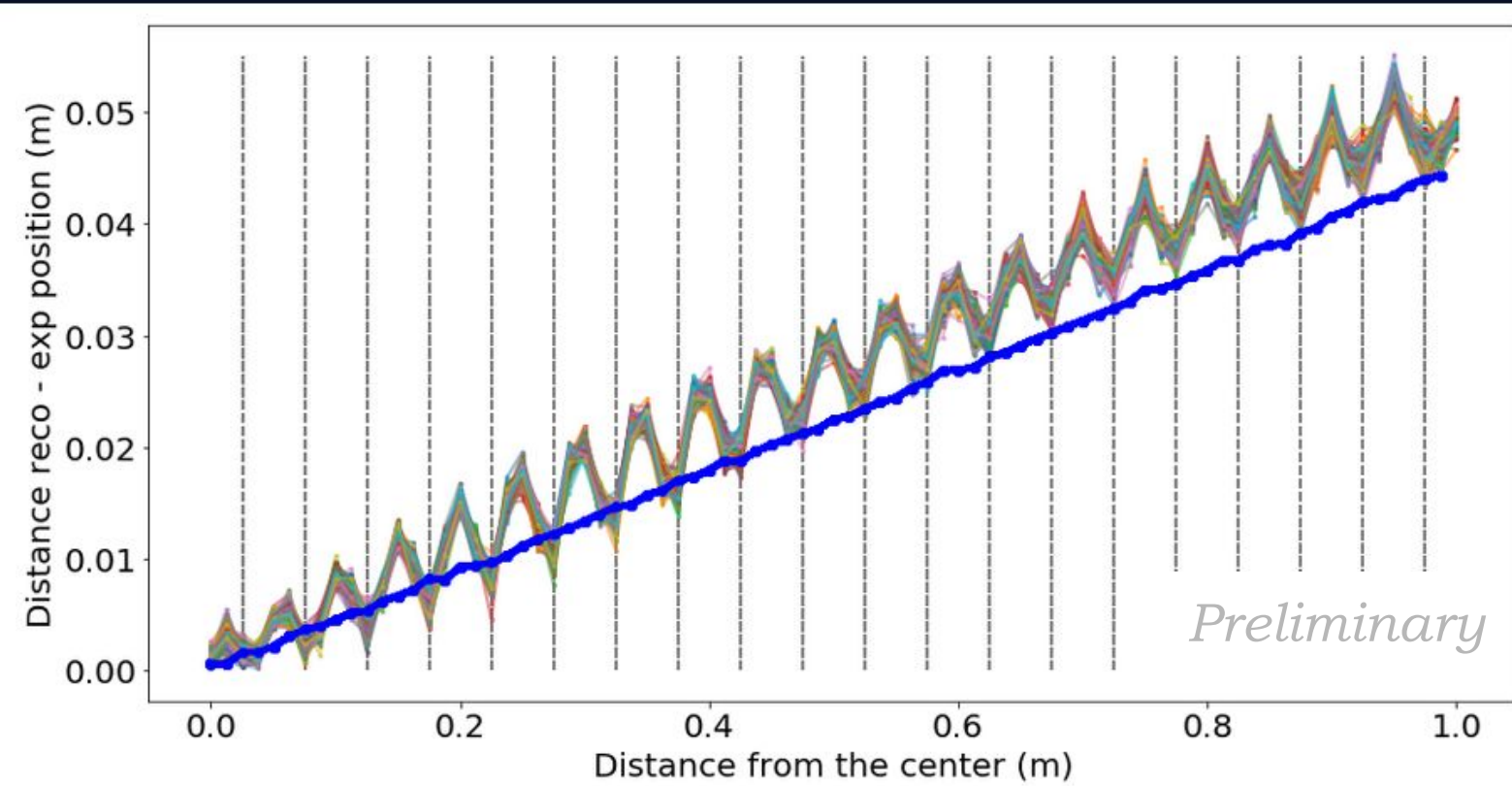


Fig 3: The systematic effects that affect the star reconstruction are analyzed through simulations with sim_telarray (K. Bernlöhr + 2008) and then applied to the real-data analysis. In this plot, a periodic oscillation of the distance between the reconstructed and the simulated star as a function of its distance from the center is investigated.

Two approaches

This method was already investigated with similar applications by the ASTRI and the HESS Collaborations. In our specific application, we developed two different approaches, depending on the time scale of the systematics that have to be monitored.

High-frequency approach:

The method is applied on data with a timescale of about one **second**. During this time interval, the stars are considered fixed with respect to the field of view.

- ❑ The minimization of the distance between the two grids of stars (reconstructed and expected) is performed with a vectorial term (**translational** fit)



Low-frequency approach:

The method is applied to data sets with a time-scale of some **minutes** of observation. The rotation of the stars in the FoV is not negligible (Fig.2).

- The minimization of the distance between the two grids of stars (reconstructed and expected) is performed with a **rotational** fit.
- The free parameters of the rotational fit are
 - the average offset at which each star is located in the camera
 - the fixed rotation center of the images, that is assumed to be the pointing direction in the camera frame.

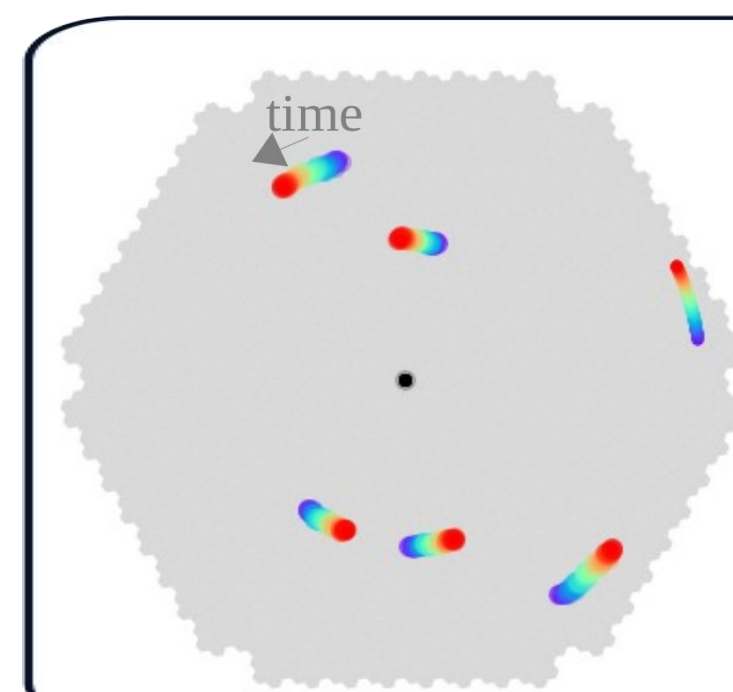


Fig 2: representation of the application of the method with the low-frequency approach. The rotation of the stars inside the FoV is identified and used to estimate the rotation center by means of a rotational fit. The rotation center of the images is assumed to be the reconstructed telescope position in the camera frame. The color palette from blue to red represents observations of about 10 min.

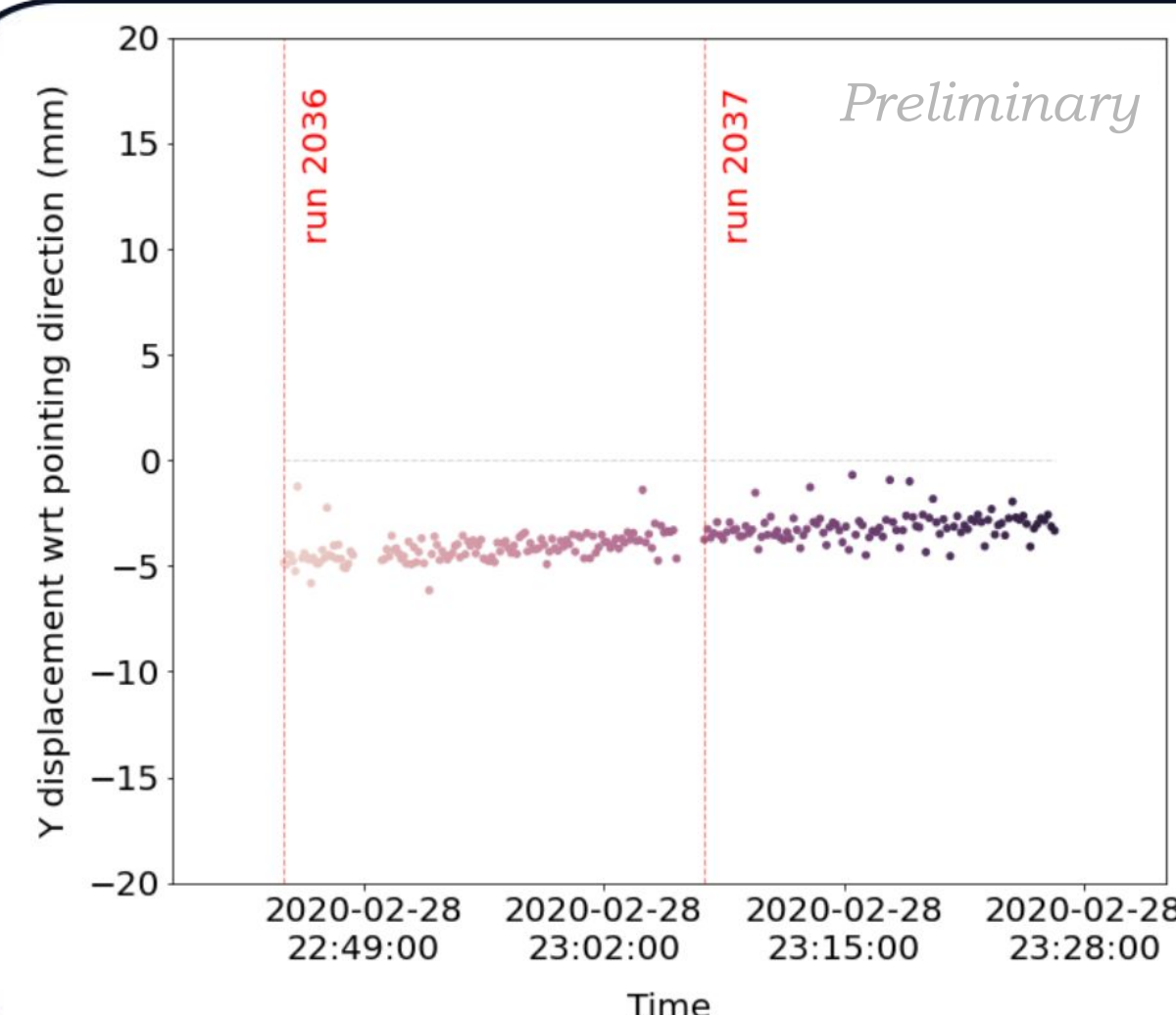


Fig 4: The vertical camera displacement in the camera frame as measured as a function of time over two data runs taken on 28/02/2020. Its dependence on the zenith angle of the observation - reported with the color scale - is due to the contribution of the weight of the camera to its position with respect to the optical axis of the telescope, and it is in agreement with the results obtained with other methods. Statistical errors are included, systematic errors under study (Fig. 3).

Conclusions and open points

In this work, we investigate an alternative method to monitor the pointing accuracy of the LST-1 prototype. This method uses the position of the stars in the field of view obtained from the events registered during normal data-taking runs. By minimizing the distance between the reconstructed star positions and the expected positions obtained from the catalogues, the pointing direction can be derived. The results we obtained show the feasibility of the method and are in agreement with other methods. Nevertheless, the control over the systematic effects related to the single-star reconstruction is being improved. The robustness and the reliability of the procedure is undergoing a detailed cross-check by using a specific set of simulations to reconstruct the camera behavior and several patterns of stars for different pointing directions. This method is currently under development for the specific requirements of the LST-1 prototype. However, making use of real Cherenkov data, it could potentially become a tool of general utility for different types of telescopes within the CTA, even when they are not equipped with specific devices to monitor the pointing accuracy.