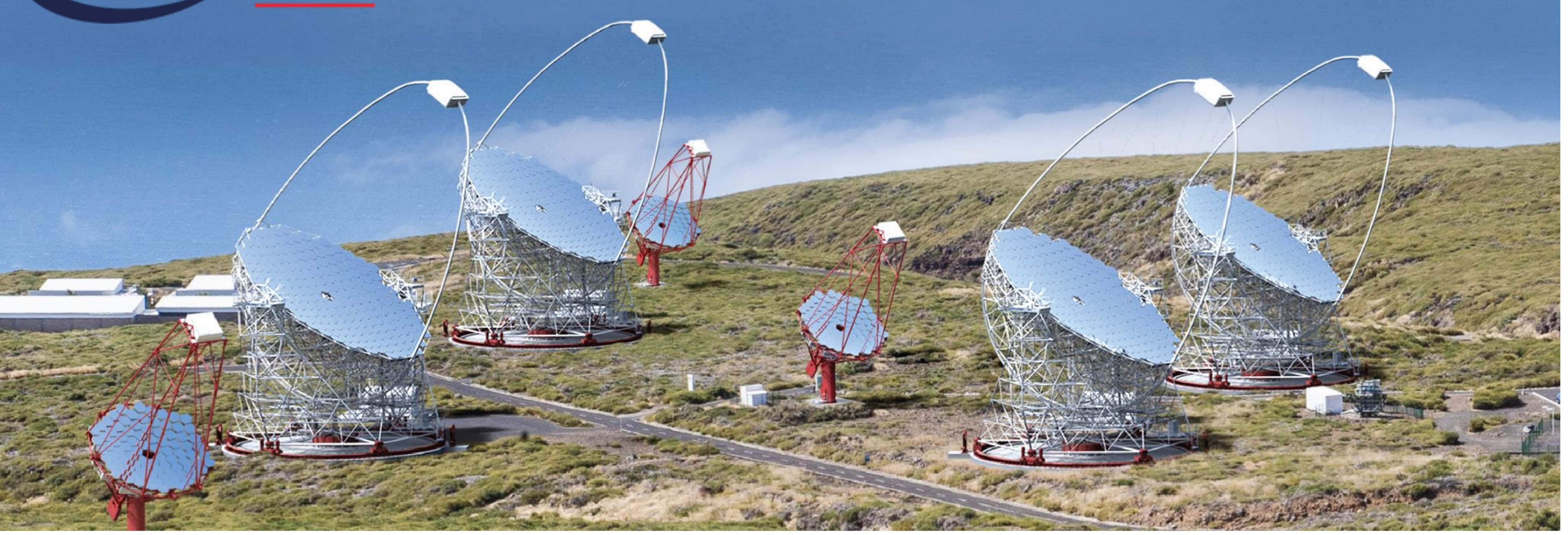

Monitoring the pointing of the prototype LST-1 using star reconstruction in the Cherenkov camera

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Abstract

The first Large-Sized Telescope (LST-1) proposed for the forthcoming Cherenkov Telescope Array (CTA) has started to operate in 2019 in La Palma. The large structure of LST-1 - with a 23 m mirror dish diameter - imposes a strict control of its deformations that could affect the pointing accuracy and its overall performance. According to CTA specifications that are conceived to resolve e.g. the fine structure of galactic sources, the LST post-calibration pointing accuracy should be better than 14 arcseconds. To fulfill this requirement, the telescope pointing precision is monitored with two dedicated CCD cameras located at the dish center. The analysis of their images allows us to disentangle different systematic deformations of the structure. In this work, we investigate a complementary approach that offers the possibility to monitor the pointing of the telescope during the acquisition of Cherenkov data. After properly cleaning the events from the Cherenkov showers, the reconstructed positions of the stars imaged in the camera field of view are compared to their nominal expected positions in catalogues. This provides a direct measurement of the telescope pointing, that can be used to cross-check the other methods and as a real-time monitoring of the optical properties of the telescope and of the pointing corrections applied by the bending models. Additionally, this method benefits from not relying on specific hardware or dedicated observations.

In this contribution we will illustrate this analysis and show results based on simulations of LST-1.

Introduction

The LST-1 represents the first prototype of Large-Sized Telescopes (LSTs), that will be the largest telescopes of the Cherenkov Telescope Array (CTA).

In order to maintain the required pointing accuracy better than 14 arcseconds, its pointing direction is traditionally monitored by specific devices: the starguider camera (SG), the camera displacement monitor (CDM), and four distance meters. These devices monitor the deformations and the mispointing during the data taking, and their information is used to apply offline corrections to the data. On the other hand, the online corrections rely on the elaboration of a specific bending model, that represents a set of instructions applied to the drive system during the observations in order to automatically compensate for deviations due to the structure bending.

The star tracking method

In this work, we systematically apply a complementary and more direct technique called "star tracking" method, that uses the stars in the field of view (FoV) during the data taking as a monitoring tool.

Among the different possible applications, such a technique is intended to provide a monitoring of the telescope pointing accuracy and an independent cross-check of the corrections applied with the bending model, and offers the following advantages:

- This method does not require any additional hardware or any specific technical observation time. It can be applied to **archival** data (also retroactively to provide a historical analysis) or as a **real-time** monitoring system during the normal data taking.
- With a standard data-taking frequency of about ~8-10 kHz, the method monitors the pointing direction with a frequency potentially higher than the other conventional methods.
- 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 alignment of the mirrors.

How it works

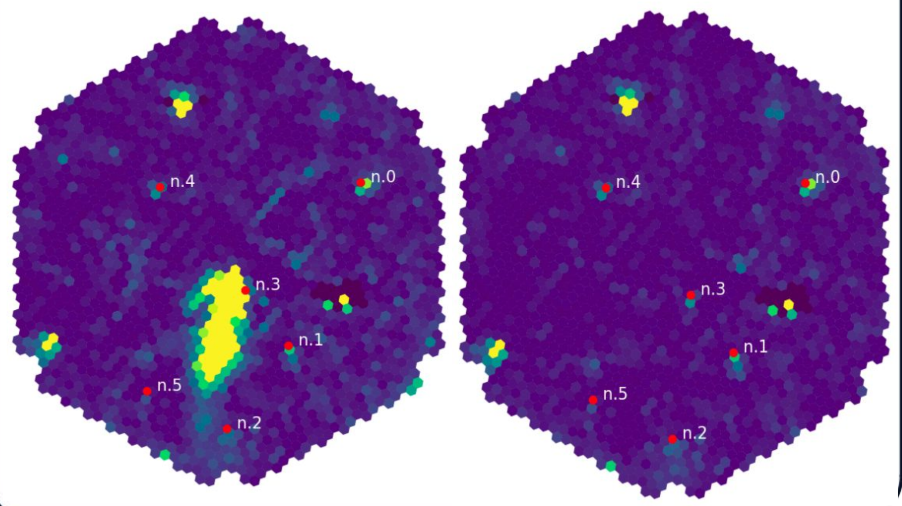
The pipeline works on all the **events** triggered by the telescope. In order to keep only the background, each event is properly cleaned from the contamination of the Cherenkov shower (Fig.1).

In order to increase the signal to noise ratio, we consider the variance of the waveform provided by the each camera pixel. After the cleaning, several events are averaged to form an ***image*** of the camera.

The position of the stars in the camera frame is reconstructed by detecting the hotspots corresponding to the expected positions of the stars, as converted from the astronomical catalogues.

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).*



Pointing direction estimation: two approaches

During the observations, the stars in the FoV follow along a partial circular trajectory centered on the average pointing of the telescope. Such trajectories can be used to monitor the actual pointing of the telescope: the rotation center is assumed to be the reconstructed telescope position in the camera frame (*low-frequency approach*). Alternatively, when the rotation of the stars is negligible, the comparison between the measured position of the stars in the FoV and their expected positions from catalogues is used to provide an estimation of the pointing of the telescope (*high-frequency approach*).

<u>Low-frequency approach:</u>

We analyse the data over minutes time scale: the rotation of the stars in the FoV is not negligible (Fig.2 left). The minimization of the distance between the grids of reconstructed and expected stars is performed with a **rotational** fit.

<u>High-frequency approach:</u>

The method is applied to data over ~ **second** time scale: the stars in the FoV are considered fixed, and no rotation is detectable (Fig.2 right).

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

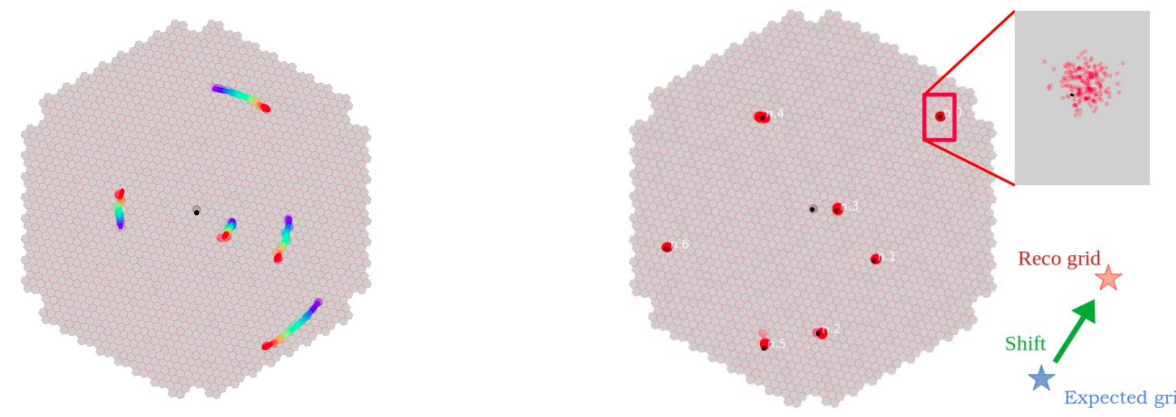


Fig 2: *representation of the application of the rotational fit in the low-frequency approach (left) and of the translational fit in the high-frequency approach (right)*

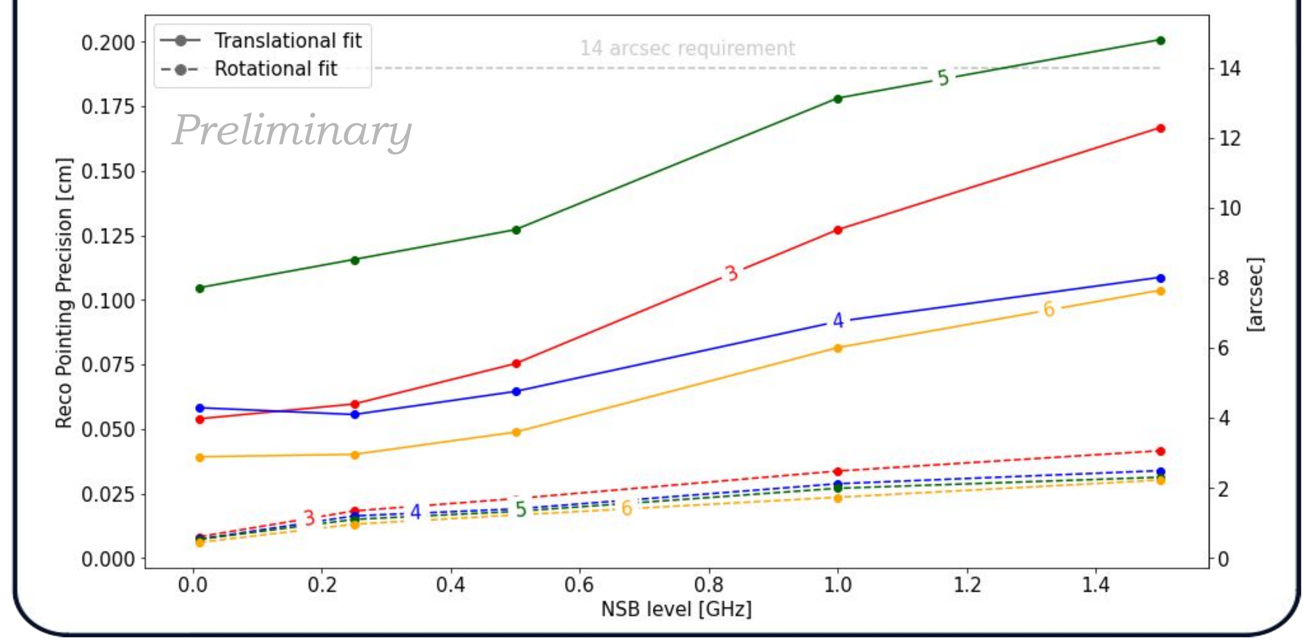
Preliminary precision

Several types of dedicated simulations have been performed using *sim_telarray* in order to study the precision of the method.

In this contribution, we present the preliminary results obtained by means of simulations of simplified patterns of 3, 4, 5, and 6 stars, scanning over a wide range of free parameters such as night-sky background (NSB), star intensity and distance from camera center (in Fig.3 the results over the NSB scan are reported).

Although not comparable with the resolution of standard pointing monitor devices such as the CCD starguider camera, the achieved resolution for these simplified configurations fulfills the requirement limits requested for LST pointing precision confirming the method as a valid and complementary alternative for telescopes pointing monitoring.

Fig 3: *Precision of the method over different levels of NSB*



Conclusions and open points

In this work, we present the systematic application of the star tracking method to the LST-1 telescope. This pipeline uses the position of the stars in the field of view obtained from the events registered during normal data-taking runs. Among the several applications, in this work we studied the monitoring of the telescope pointing accuracy. By minimizing the distance between the reconstructed star positions and the expected positions obtained from astronomical catalogues, the pointing direction can be estimated. Thanks to the development of dedicated simulations, we have shown that the precision of the method under good-quality dark observations and simplified configurations of stars respect the CTA requirements on the pointing accuracy of the telescope. Further studies are being developed in order to verify the resolution of the method also under more general star patterns. Thanks to the fact that this method analyses the raw data without requiring specific observations or devices, it could potentially become a tool of general utility for different types of telescopes within the CTA.

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