TITLE: **LSPE-STRIP: Estimation of star tracker optimal parameters**

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ACRONYMS

Acronym	Meaning
TBD	To be defined
TBC	To be confirmed
STR	Star Tracker
FOV	Field of View

1 APPLICABLE AND REFERENCE DOCUMENTS

1.1 Applicable Documents

1.2 Reference Documents

2 Scope of the Document

This document[1] describe the statistics needed to optimize the Star Tracker (STR) design for LSPE-STRIP.

A Star Tracker (STR) is a device used to determine the instantaneous pointing direction of the telescope, by looking at stars observed in the sky.

Pointing direction is the direction at which the telescope optical centre is aimed.

The STR is made of three components:

1. optics, aligned with the telescope optical centre (or off-setted of a known amount)
2. imager, able to collect an image of the stars observed on the sky
3. processor, able to process the images, store them and communicate with the telescope control system

The work presented here is aimed at the optimization of optics and camera parameters.

In particular, the relevant optics and camera parameters must be optimized looking at the number of stars observed per frame by the STR.

In this run no simulation of camera electronics is carried on.

In this run no atmospheric refraction is accounted for.

[1] This work is partially based on the work of Matteo Porru for his "Tirocinio" as an undergraduate student at the Trieste University Physics Department, hosted at Trieste Astronomical Observatory from October 15th to December 15th 2017.

3 Method and validation

The simulation is based on a model of the sky with its diurnal and seasonal variation.

The telescope is assumed to scan during the night the sky according to a predefined scanning strategy.

The sky is framed either in rings of constant zenith angles and constant widths or in frames corresponding to the STR Field of View (FOV).

Stars in each ring or frame are counted.

To validate the code the observed star counts was simulated against a model sky containing a uniform distribution of stars. In this hypothesis $N_{avg}=\frac{N\,sin(inc)}{2}FOV$. This was verified using a uniform HEALpix distribution of 196000 stars, calculating results in the range 10° - 40° of inclination and 2°, 4°, 8° of FOV.

4 Results and Conclusions

1. The goal of the simulations was to estimate the number of stars present in each frame as a function of the limit magnitude. As an intermediate step, a simple star count per ring was generated for each scan.

2. The simulation assumes a simple scanning strategy, with the telescope rotating at 1 R.P.M. around the zenithal axis, and with fixed angular distance between the zenith and the center of the FOV of the STR, *Z*. In this way, the STR scans a circular ring around the zenith, which from now on we will refer to as *ring*.

3. Stars for the simulation are derived from Star catalog Tycho-2 (http://vizier.u-strasbg.fr/cgi-bin/VizieR-3?-source=I/259/tyc2) truncated at the 10th magnitude.

4. Simulations are done for FOV=3° and 6° and for *Z*=15°, 20°, 25°, from 2018 August 1st to 2019 August 1st, for the Teide National Observatory site (neglecting atmospheric refraction).

5. The nominal use case is FOV=6° and Z=20°.

6. In the nominal case we have, for limiting magnitude (m_lim) equal to 6, a minimum of 40 stars per ring and a maximum of 128 stars per ring, with 78 as an yearly nocturnal average.

7. This translates into 3.804 stars per frame on average, which is consistent with the expected value of 3.801, obtained with simple geometrical considerations from the average per ring.

8. More relevant to the scope of our observations is the number of frames containing 0, 1, 2, 3 or more stars, i.e. the *sky coverage*. At the 6th limit magnitude, the fraction of frames containing 3 or more stars fluctuates between 55% in August and 73% in February. The fraction of empty frames is around 3%.

9. Increasing the limiting magnitude to 7 yields significantly better results: the number of stars per ring fluctuates in the interval [134, 357], with an average of 245.

10. The average number of stars per frame increases to 11.943, which is consistent with the expected value of 11.939.

11. With m_lim=7, the fraction of frames with 3+ stars varies between 97% and 99.7%, with no empty frames.

12. In the worst-case scenario of m_lim=5 the number of stars per ring varies in the interval [10, 46], with 24 as average. This means only 1.17 stars in each frame, on average.

13. Only 8-18% of the frames contain 3 or more stars, and 30-40% of the frames are empty.

14. A change in FOV from 6 deg down to 3 deg has a significant effect. From planar geometry, we expect the number of stars per ring to halve, while the number of stars per frame should reduce of a factor four. Simulations show an agreement within 3%. The differences are due to the non-uniform distribution of stars in the sky and to projection errors. In order to get the same level of sky coverage obtained with FOV=6 deg and m_lim=6 it is necessary to increase m_lim to a value between the 7^{th} and the 8^{th} magnitude.

15. A change in Z in the range [15°, 25°] does not affect the previous results in a significant manner. There is not a systematic change in the fractions of frames with 0, 1, 2, 3, 3 or more stars varying Z. the mean number of stars per frame changes at most of about ten percent.

16. Our findings about star counts can be summarized by the following formula:

$$\log_{10}\langle n\rangle = A\, m_{\mathrm{lim}} + C \log_{10}\left(\frac{\mathrm{FOV}}{3°}\right) + D$$

Where A=0.5, C=0.963, D=-1.49 for counts per ring, while in the case of counts per frame we have A=0.505, C=1.927, D=-3.1.