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# Alignment of the Mirror Facets of the H.E.S.S. Cherenkov Telescopes

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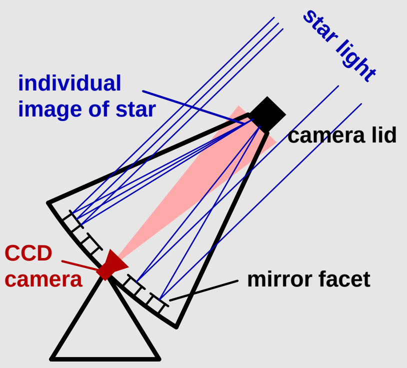
## Abstract

The H.E.S.S. project is one of the next generation instruments for very high energy (VHE) gamma-ray astronomy. A stereoscopic system of four Imaging Atmospheric Cherenkov Telescopes (IACTs) with a mirror area of about $100\,\mathrm{m}^2$ is currently build up in the Khomas Highlands of Namibia. Each reflector will consist of 382 individual mirror facets. These are quartz-coated, aluminized and equipped with a support-drive unit which is controlled by a dedicated system to provide an automated alignment. Tests showed that for individual light spots in the focal plane a positioning accuracy of better than $0.05$ mrad can be achieved.

## Mirror Alignment Technique

The concentrator of each Cherenkov telescope consists of 382 mirror tiles, each equipped with two DC motors to provide together with the feedback by a CCD camera an automated alignment system. This uses images of stars on the telescope camera lid to monitor the position of the mirror tiles.

### The basic concept




1. Take a CCD snapshot of the image of a star on the camera lid generated by all mirror facets.
2. Move a specific mirror facet by a large distance compared to the spot size.
3. Take a second CCD snapshot.
4. Determine the exact spot positions corresponding to the specific mirror facet by subtracting one snapshot from the other.
5. Calculate the distance from the target position and move the mirror facet accordingly.

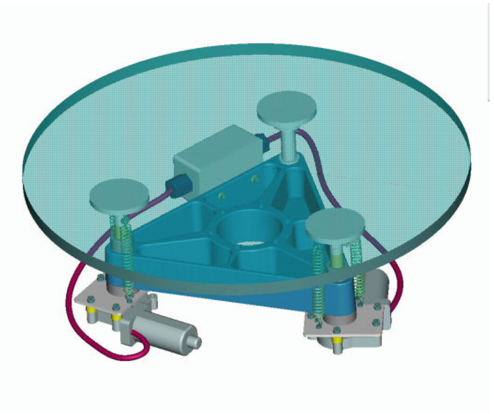
## Requirements

The accuracy of the mirror alignment as well as the stability of the mirror support are essential for the quality of the data which will be taken with the H.E.S.S. stereoscopic system. The requirements on the mirror-support drive and on the automated alignment system are:

- No stress on the mirror.
- The pointing accuracy of a mirror less than $0.1$ mrad (corresponding to $0.2$ mrad for the light spot in the focal plane).
- Individual mirrors adjustable over a range of $\pm 17.4$ mrad.

## The Mirror Support Drive Unit

- Mirrors held in place by special joints to avoid stress.
- Support equipped with two actuators, each with one DC motor.
- Each motor has two Hall sensors to monitor movements.
- Resolution of actuator movement: $3.4\,\mu$m (equal to $0.013$ mrad).
- Range of adjustment: $\pm 54$ mrad in x- and y-direction.



### Acknowledgements

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### References

*W. Hofmann*, Alignment of the HESS mirrors using images of stars, H.E.S.S. internal note (1998)
*W. Hofmann*, Design considerations for the HESS mirror supports and drive mechanisms, H.E.S.S. internal note (1998)
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## Tests of the Mirror Alignment System

All components of the mirror alignment system have been tested extensively (deviations are stated in respect of the position of the light spot in the focal plane):

- No indication of stress on the mirror has been found when measuring the angular resolution and spot shape before and after gluing and mounting the mirrors on the support.
- The measured deformation of the support and mounting when changing the zenith angle is $(0.022 \pm 0.006)$ mrad under a load of $5.5$ kg.
- Tests in a climate chamber showed, that the effect of the extreme climate in Namibia is negligible.
- Accuracy and reproducibility of the mirror positioning have been tested on a mounted complete mirror support unit. The image of a laser pointer on a screen was monitored with a CCD camera (pixel size $0.18$ mrad) under repeated interleaving operation of both actuators. A positioning reproducibility of $0.017$ mrad (RMS) was achieved.
- The alignment accuracy for a light spot in the focal plane produced by a central mirror facet is $0.023$ mrad (RMS).
- Tests of the motor control hardware showed that no spurious Hall counts occurred, that the motors can be moved the predetermined number of Hall counts and that the security shut off works reliable.

## Alignment Algorithm, Simulations and Results

Position $\vec{x}$ of an individual light spot in the focal plane for a given elongation $\vec{a}$ of the actuators.

$$\vec{x} \equiv \binom{x_1}{x_2} = f(q_1, \ldots, q_n, \vec{a} \equiv \binom{a_1}{a_2})$$

$q_i$: position / orientation of mirror

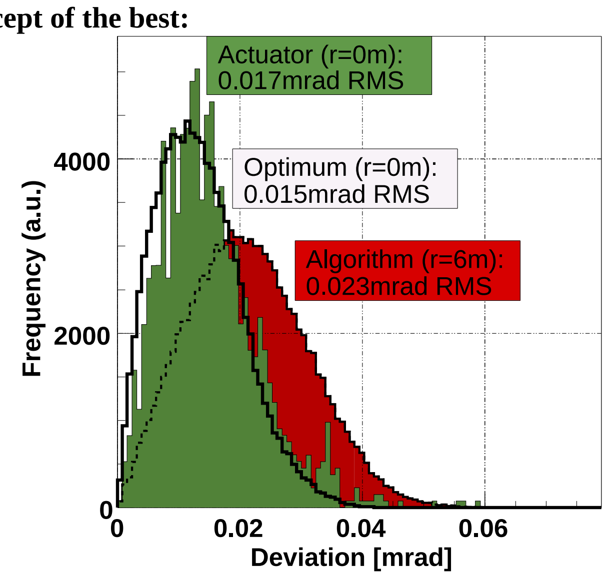
Linear approximation to determine the change in $\vec{a}$ needed for a desired change in $\vec{x}$:

$$\overrightarrow{\Delta x} = \underline{T}\ \overrightarrow{\Delta a}$$

$$\Longrightarrow \overrightarrow{\Delta a} = \underline{T}^{-1}\ \overrightarrow{\Delta x}$$

The transformation matrix $\underline{T}$ is determined by driving both actuators ($a_1$, $a_2$) individually for a certain number of Hall counts while imaging the change in $\vec{x}$ with the CCD camera. Several alignment algorithms have been studied using Monte Carlo simulations. Concept of the best:

1. A rough transformation matrix is determined at the position of the light spot.
2. Using this transformation, the mirror is moved to four positions surrounding the nominal position to get a more accurate matrix.
3. This is used to move the mirror to its target position.




The filled green histogram shows the measured positioning accuracy of a light spot produced by a central mirror facet, the open one the corresponding simulated optimum, and the red the simulated alignment accuracy for an outer mirror.

## Conclusion

Simulations based on the resolution of the actuators showed that a positioning accuracy of $0.015$ mrad (RMS) can be achieved. Mechanical play and the finite resolution of the CCD camera broaden the distribution somewhat: a positioning accuracy of $0.017$ mrad (RMS) has been measured. Monte Carlo simulations, which neglected the finite resolution of the CCD camera (pixel size will be $0.05$ mrad in the final setup) and the mechanical play, led to an alignment algorithm with an overall deviation of $0.023$ mrad (RMS). This is consistent with test measurements on a central mirror, which resulted in a deviation of $0.023$ mrad (RMS). Taking into account the additional deviation resulting from the bending of the mirror support under different zenith angles ($0.022$ mrad), one concludes, that all requirements are fulfilled.