Design and Development of an Automatic Mirror Segment Alignment System

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Outline

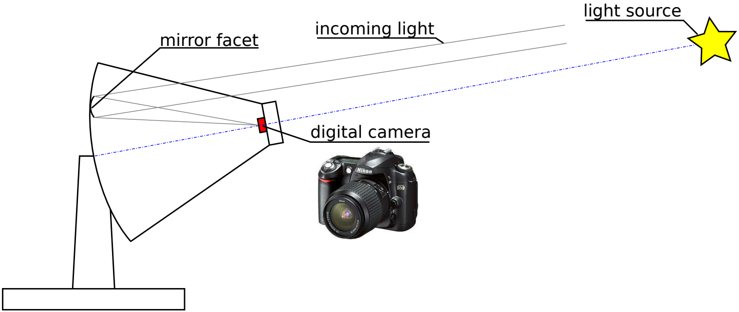
Motivation

Mirror facets needs to be aligned:

- closed loop alignment system
- take advantage of the actuators
- do a simultaneous alignment for all mirror facets
- realignment after deformation and/or installation

How to align the mirror facets?

- additional digital camera in the focal plane facing the mirrors
- telescope points to an artificial light source or a star
- camera sees all mirror facets. The properly aligned facets appear bright, the misaligned dark
- with actuators, a realignment with *live* feedback can be done



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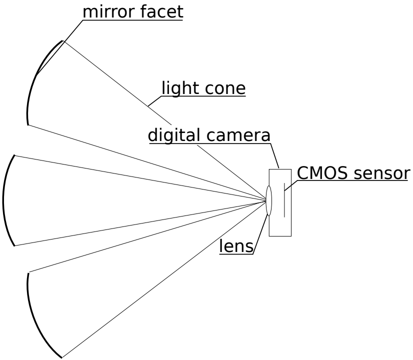

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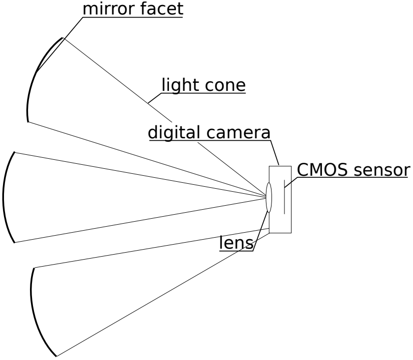
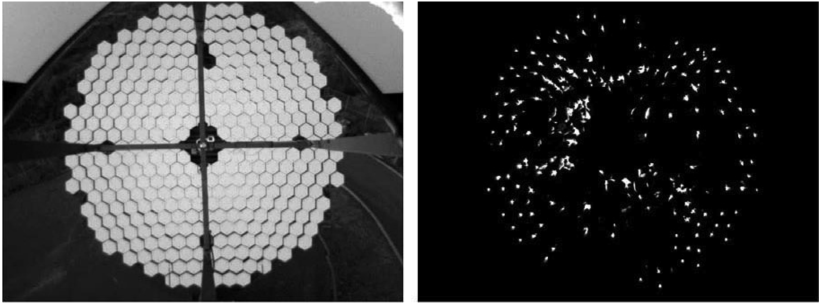


VERITAS Example

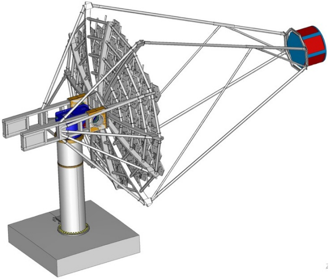


View of the digital camera at the VERITAS telescope

A. McCann et al. (2010). Astroparticle Physics, 32(6), 325–329.

Simulation

- simulation of the sensor illumination
- input parameters:
  - mirror quality (reflection eff., point spread function)
  - mirror alignment
  - camera lens (aperture, focal width, etc)
  - camera position
  - camera rotation
  - brightness of the source
- simulation done for a prototype



middle size telescope prototype

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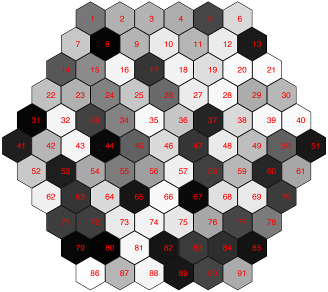
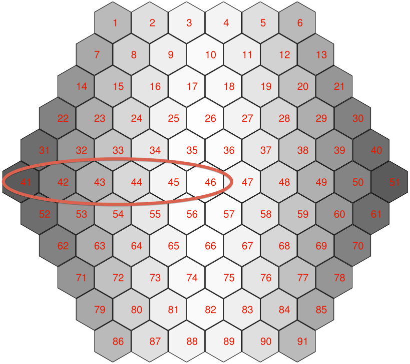
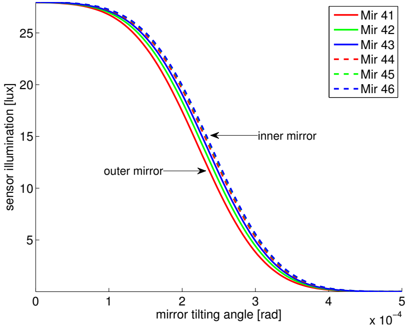


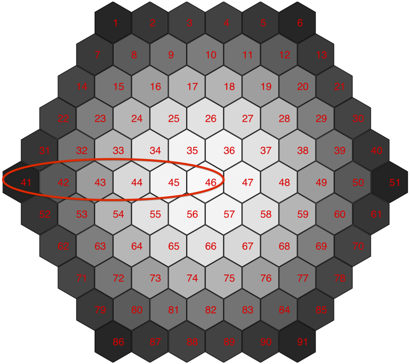
Simulated image from a digital camera with randomly aligned mirrors

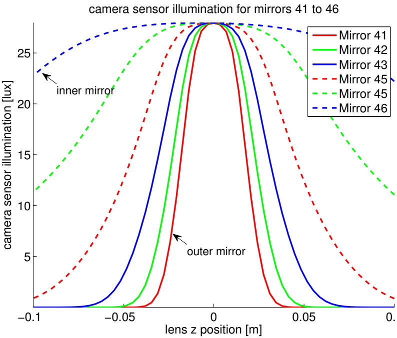
- Illumination changes when the mirror facets are tilted
- Light source with apparent magnitude 0 assumed
- Camera is centered in the focal plane.





- Illumination changes when the camera is moved along the telescope's optical axis
- Light source with apparent magnitude 0 assumed
- Camera-lens ± 10 cm from focal point of mirror 46 displaced





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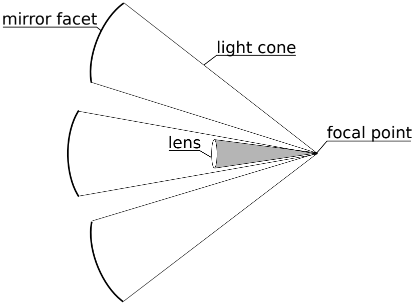
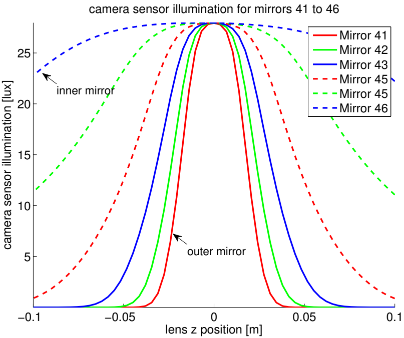




Test Setup

- setup to develop and test alignment algorithms
- optical rail
- tiltable mirror
- digital camera with integrated CPU

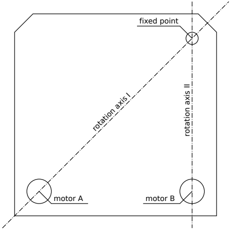
Digital Camera

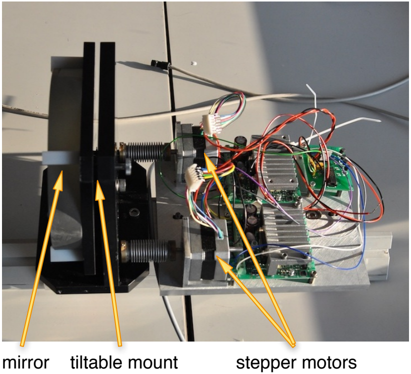
- CMOS sensor with 752 x 480 pixel
- a camera with an embedded 500 MHz CPU is used
- interfaces: I^2C, Ethernet, two opto-coupled in- and outputs.
- image analysis done on camera
- the camera controls the actuators

$\Rightarrow$ Standalone System

Mirror and Mirror Mount

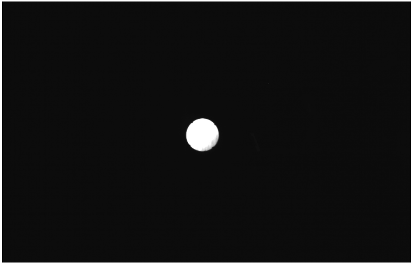
- shape: parabolic
- diameter: 10 cm
- focal length: 1.5 m
- tilting resolution per motor-step
  - axis I: 0.049 mrad
  - axis II: 0.035 mrad





Camera View

illuminated environment

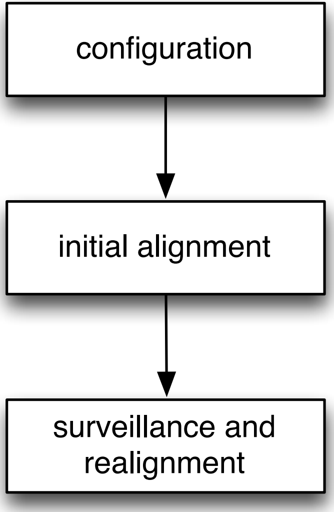


Mirror is close to proper alignment

Software Specifications

- Software Requirements:
  - Initial mirror alignment
  - Real time mirror surveillance and resetting the mirror orientation after a deformation of the telescope
  - Everything can be done simultaneously for all mirror facets.
- Limited Hardware:
  - Simple algorithms needed
  - Low memory usage

- configuration:
  - mirror position in picture
  - scanning resolution
  - drive range
- initial scan to search for the highest illumination
- realignment after illumination decreases below 3σ



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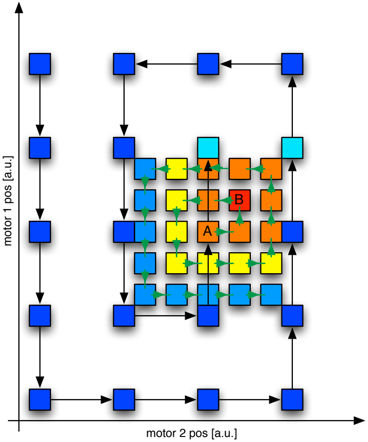

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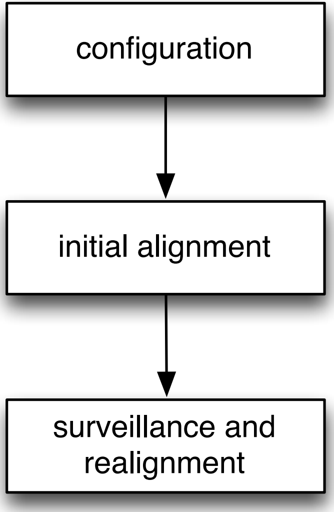
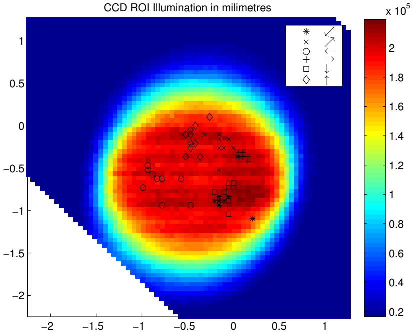


Software Testing

- Tests with artificial light source:
  $\Rightarrow$ Tower with position light at about 2 km distance
- Mirror has been displaced manually in different directions and the application is asked to realign



Data Analysis with Sirius

- test setup pointed to Sirius (-1.46 mag)
- calculation of the luminous flux from the sensor data
    - comparison to simulation

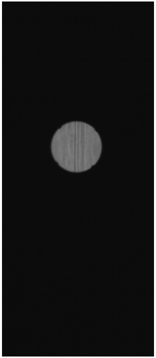


image taken while pointing to Sirius

Realignment Time

- realignment time depends on size of deformation.
- test setup: between 1 s and 2 min
- depending on actuator's speed and range to drive, scanning resolution, settling time of the whole structure
- natural oscillation modes of the telescope structure
  $\rightarrow$ averaging of pictures needed

Conclusions

Advantages:

- simultaneous alignment for all facets possible
- only simple and cheap hardware needed
- only minimal changes in the focal plane needed

Disadvantages:

- camera cannot estimate how far a mirror is misaligned if it is completely dark
- distant light source needed