



The Active Mirror Control of the MAGIC Telescope

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Abstract: One of the main design goals of the MAGIC telescopes is the very fast repositioning in case of Gamma Ray Burst (GRB) alarms, implying a low weight of the telescope dish. This is accomplished by using a space frame made of carbon fiber epoxy tubes, resulting in a strong but not very rigid support structure. Therefore it is necessary to readjust the individual mirror tiles to correct for deformations of the dish under varying gravitational load while tracking an object. We present the concept of the Active Mirror Control (AMC) as implemented in the MAGIC telescopes and the actual performance reached. Additionally we show that also telescopes using a stiff structure can benefit from using an AMC.

Introduction

The MAGIC telescope [1] is installed at the Roque de los Muchachos on a height of ≈ 2200 m a.s.l. on the Canary Island La Palma. Having a reflector area of 236 m^2 , it is by far the largest existing imaging Cherenkov telescope. One of the main goals in the design of the MAGIC telescope was the ability to point to any arbitrary position on the sky in less than 20 s to allow e.g. the observation of GRB immediately after an alert from satellite experiments. To achieve this goal, a stiff, lightweight frame structure made of carbon fiber epoxy tubes was built to minimize the telescope's weight. When pointing the telescope to different zenith angles, the reflector's surface undergoes small deformations under varying gravitation loads. To correct for this effect, the individual mirror-segments must be realigned [2, 3].

Implementation

The reflector of the MAGIC telescope consists of 956 square shaped mirrors with a size of $49.5 \times 49.5 \text{ cm}^2$. Four (at the edges three) mirrors are mounted and adjusted on one of 247 panels.

These panels are attached to the carbon fiber support frame at three points; one of these points has a fixed distance, while the other two are equipped with longitudinally movable actuators having a lateral freedom of one and two dimensions respectively. Each actuator contains a two phase stepping motor and a ball-bearing-spindle, allowing to move the panels with a precision $< 20 \mu\text{m}$, corresponding to a displacement of the light spot at the camera of less than 1 mm. To monitor the orientation of a panel, each one is equipped with a guidance laser module, pre-adjusted to point to the target of the panels (figure 1).

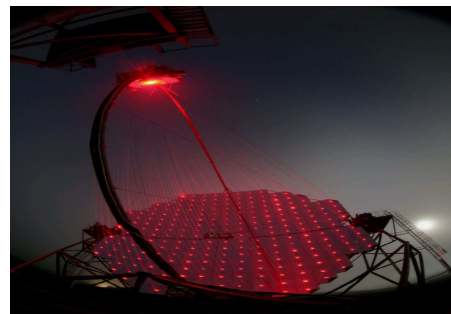


Figure 1: MAGIC telescope with all AMC guidance lasers switched on.

As illustrated in figure 2, the AMC also includes four LEDs on the PMT-camera lid as reference points and a CCD-camera mounted on the reflector frame close to its center. The electronics to handle the actuators and lasers is housed in 62 water tight boxes and the connection to the control computer is split into eight independent RS-485 strings to allow for parallel operation.

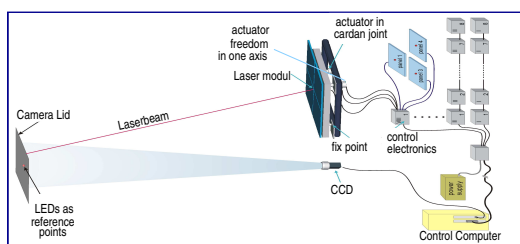


Figure 2: Components of the Active Mirror Control. See text for details.

Initial Mirror Alignment

In a first step it is needed to calibrate the full system, i.e. to find the correlation between the movements of the stepping motors and the displacement of the reflected light. This is done by measuring the position of the laser spot for several stepping motor positions for each panel.

Next, one has to find the best mirror alignment for one telescope orientation. Originally, this was done using a bright, artificial point-like light source pointing towards the telescope and adjusting each individual panel manually so that the light is reflected to the center of the PMT camera. Then the camera-lid was closed, each laser switched on sequentially and the position of the laser spot on the lid relative to the LEDs as measured by the CCD is stored as reference point. Unfortunately, the farthest possible place to mount the artificial light source is only 980 m away from MAGIC. While for a spherical reflector it would be sufficient to move the PMT-camera 27 cm closer to the dish to change the focal length from 980 m to 10 km, this is not enough in the case of a paraboloid: the outermost panels would still point as much as 25 mm off target. Therefore, a higher order correction had to be calculated and applied to these reference points. An additional problem was that the (tempor-

rary) mounting of the light-source was not exactly reproducible and therefore existed the risk to introduce an artificial miss-pointing of the telescope.

To overcome this restriction, the CCD-camera was upgraded to higher sensitivity to be able to see the reflection of a single panel while tracking a bright star. Additionally, a mechanism to position a highly reflective panel in front of the PMT camera was installed. By completely defocusing all but one panel, it is therefore possible to find the best alignment. But since this procedure needs several hours and the stars visible under small zenith angles move rather fast and have to be tracked by the telescope, this does not result in a focusing for one fixed zenith angle. Therefore, a method was developed to defocus about 30 panels according to a pre-calculated grid arrangement (and completely defocus the remaining ≈ 210 panels) as shown in figure 3. As long as the displacement of the light spot of a panel is less than ≈ 3 cm, it can be identified and a correction be calculated and applied. Since this needs only 8 measurements to control the alignment of the 247 panels it can be completed in few minutes and the movement of the telescope can be neglected.

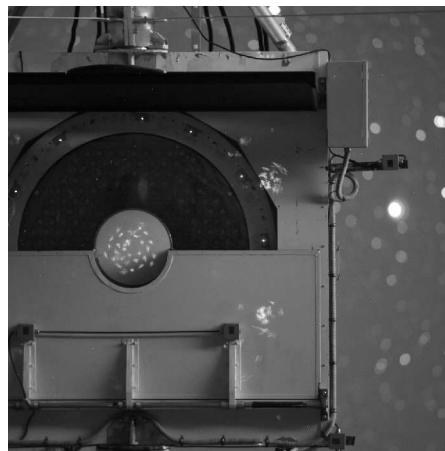


Figure 3: Light-spots of 30 mirror tiles defocused to a pre-calculated pattern on a reflector at the center of the PMT camera.

After knowing the best alignment of each panel for one given zenith angle, the position of the spot of the guidance laser for each panel is stored in a database and used to transpond the alignment to different zenith angles.

AMC Operation Modes

In the basic *laser adjustment* mode of the AMC, the following steps have to be done:

- a) close the camera-lid (to be used as screen for the laser spots as well as to protect the PMTs from the lasers)
- b) activate the CCD and search for the LEDs that define the center of the camera
- c) sequentially for each panel: activate the laser and move the actuators until the laser position agrees with its panel's reference point
- d) open the camera-lid and (re)start data-taking

This allows to refocus the whole telescope in about 5 min.

A time of 5 min is too slow in case of e.g. a GRB-alarm or while tracking a source. Therefore it was originally foreseen to apply such laser adjustments only when the tracking of a new source starts, and just apply a *look-up table adjustment* during the tracking. For this, a laser adjustment is done for many different telescope orientations and the positions of all stepping motors are stored in a database. From this database it is possible to extract the best position of the stepping motors for any telescope orientation. By calculating the relative change for the stepping motors between the actual orientation of the telescope and the orientation when the last laser adjustment was applied, it is also possible to take into account some time-dependent deformations of the telescope dish, e.g. because of temperature changes. Since this adjustment can be done for several panels in parallel, it takes less than 10 seconds and can be applied without interrupting the data-taking. Additionally in case of a fast repositioning of the telescope like for a GRB-alarm, it can be done while the telescope is slewing to the new orientation and the full reflector is well aligned when the telescope is ready to start data-taking.

Performance

While it is difficult to show the effect of the AMC on individual showers, it can easily be seen when pointing to stars. Figure 4a,b shows the reflected starlight on a screen in the focus point of the telescope, photographed with a high resolution CCD.

The top picture is taken with the panels pre-aligned for a zenith-angle of 80° , while the middle one shows the star after doing a laser-adjustment in the correct orientation of 22° . After adjustment, more than 85% of the light is concentrated in an area of 3.5 cm diameter, corresponding to the size of one central PMT. The total point spread function is limited by the spot size of the individual mirror tiles, while the deformation of the dish is compensated by the AMC.

Control measurements done with stars on many different telescope orientations do not only proof the optical quality of the telescope to be constant over the full zenith range, but also show no indication for any time- or temperature-dependence of the deformation of the dish. Lookup tables produced in a cold winter night are still giving good optical alignment even in hot summer. The AMC system of the MAGIC telescope has been operated in the last year with constant optical performance without the need of a new calibration.

Additional Benefits

While an AMC is more expensive than non-active mirror mounts, this can be compensated by relaxed requirements on the stiffness of the support structure of the dish.

But having the possibility to control each individual panel does not only allow to compensate deformations of the support structure, but has several other benefits:

- a) Monitoring the point spread function of a Cherenkov telescope by taking pictures from stars is not straight forward: while the star is located in infinity, Cherenkov telescopes usually are focusing to the average shower maximum of typically 10–15 km. The difference of the images of a bright star using a focal length of 10 km vs. infinity can be seen in figure 4b,c.

For spherical reflectors, this can be corrected for by moving the (heavy) PMT camera by a few centimeters or putting a temporary reflector in front of it. But for parabolic reflectors, this is not the case because of higher order corrections that have to be taken into account. Telescopes of the size of MAGIC (17 m) or larger must have parabolic reflectors to keep the time dispersion of

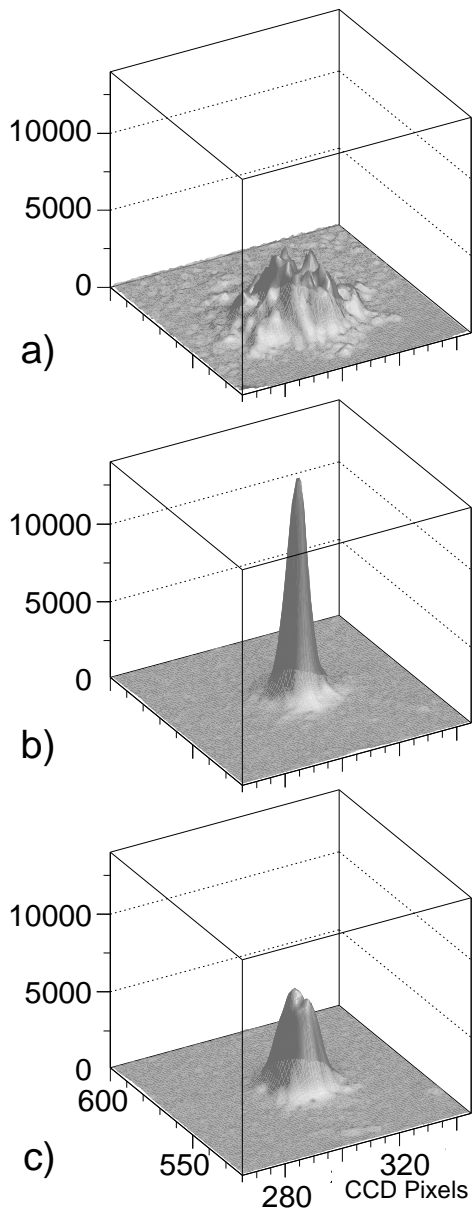


Figure 4: CCD-measurements of a bright star
 a) mirror tiles aligned to wrong zenith angle,
 b) correct alignment, focal length infinity,
 c) correct alignment, focal length 10 km

the Cherenkov signal short. So even in case of stiff reflectors, an AMC simplifies the monitoring of the point spread function.

b) An AMC can change the focal length to basically any value. Taking into account that the distance to the shower maximum depends on the zenith angle, an AMC allows to adjust the focal length during tracking¹.

c) The possibility to easily measure the reflections of a single panel (or of a group of panels as in figure 3) allows to monitor the reflectivity of each individual mirror tile. This allows to identify and replace aging parts of the reflector.

d) For daytime, it is possible to defocus all panels so far that the danger of destroying vital parts of the telescope by accidental exposition to sunlight is much reduced. This adds another security factor in case of robotic operations of future telescopes.

e) It is not only possible to change the focal length of the telescope, but also the position of the reflected spot can be easily changed. This might allow to use Cherenkov telescopes as solar power plants during day time without endangering the valuable PMT camera.

Conclusions

After some initial problems, the AMC of the MAGIC telescope is working well within the design limits. This proves that it is possible to overcome mechanical deformations of the support structure of the reflector during data taking without any degradation of the performance of the telescope. This allows to build light weight structures allowing for a very fast repositioning and/or relaxing the requirements on the stiffness of the support structure and reduce therefore the costs.

References

- [1] <http://www.magic.mppmu.mpg.de>
- [2] M. Garczarczyk et al., 28th International Cosmic Ray Conference Tsukuba, Japan (2003) 2947-2950.
- [3] A. Biland, M. Garczarczyk et al., Towards a Network of Atmospheric Cherenkov Detectors VII, Palaiseaux, France (2005) 561-565.

¹ This is not done so far in MAGIC, but will be tested during the commissioning of the second telescope