An Alignment System for Imaging Atmospheric Cherenkov Telescopes

A. McCann, D. Hanna and M. McCutcheon

Department of Physics, McGill University, H3A 2T8, Montreal, QC, Canada (mccann@physics.mcgill.ca)

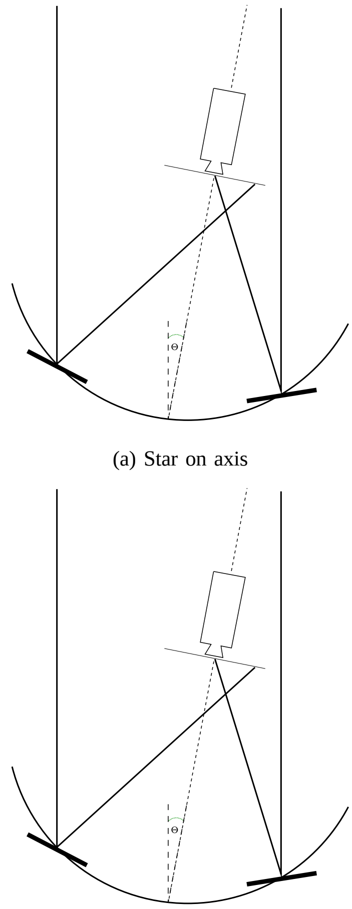
***Abstract*. The reflector used by an imaging atmospheric Cherenkov telescope (IACT) consists of a tessellated array of mirrors mounted on a large frame. This arrangement allows for a very large reflecting surface with sufficient optical quality for the implementation of the IACT technique at a moderate price. The main challenge presented by such a reflector is maintaining the optical quality, which depends on the individual alignment of several hundred mirror facets. We describe a method of measuring and correcting the alignment of the mirror facets of the reflectors used by the VERITAS telescopes. This method employs a CCD camera, placed at the focal point of the reflector, which acquires a series of images of the reflector while the telescope performs a raster scan about a star. Well-aligned facets appear bright when the telescope points directly at the star while misaligned facets appear bright when the angle between the telescope pointing direction and the star is twice the misalignment angle of the mirror. Data from these scans can therefore be used to produce a set of corrections which can be applied to the facets. In this contribution we report on initial experience with an alignment system based on this principle.**

***Keywords*: VERITAS, Alignment, Optics**

I. Introduction

Ground-based gamma-ray astronomy is a rapidly developing field in observational science which is being driven by the current generation of imaging Cherenkov telescopes operating around the world [1], [2], [3]. This generation of telescopes has built on its predecessors with improvements in several aspects of detector design, including the use of larger reflectors and larger cameras with a greater number of PMT elements. For the performance afforded by these improvements to be fully realised, the quality of the telescopes' optical alignment must be at a high level. The VERITAS array, located at the base of Mount Hopkins in southern Arizona, consists of four 12 meter diameter Davies-Cotton reflectors. Each reflector is composed of $\sim$345 hexagonal mirror facets, all of which must be properly aligned for the telescope optics to be optimal.

The exposure of the mirrors to the dust of the Arizona desert requires their periodic re-coating to maintain optimal reflectivity [4]. The drawback of this recoating procedure is that facets are regularly removed and replaced and this leads to the degradation of the telescope alignment. The telescopes must therefore be regularly realigned. This provided the stimulus to find a quick and easily implemented method of characterising and correcting the alignment of the telescopes without resorting to a costly active mirror control system. The method reported here, called the *raster method*, is based on the SCCAN technique described by Arqueros *et al.* [5].



(a) Star on axis

(b) Star off axis

Fig. 1. An illustration of the raster scan method. In figure (a) the well-aligned facet will appear bright in the CCD image while the misaligned facet will be dark. In figure (b) misaligned facet will appear bright when the angle between the star and the telescope pointing direction is twice the misalignment angle of the facet.

II. The Raster Method

The *raster method* employs a CCD camera which is placed at the focal point of the telescope, facing the reflector. The telescope is made to track a star at a typical observation elevation ($\sim$70 degrees). The telescope is

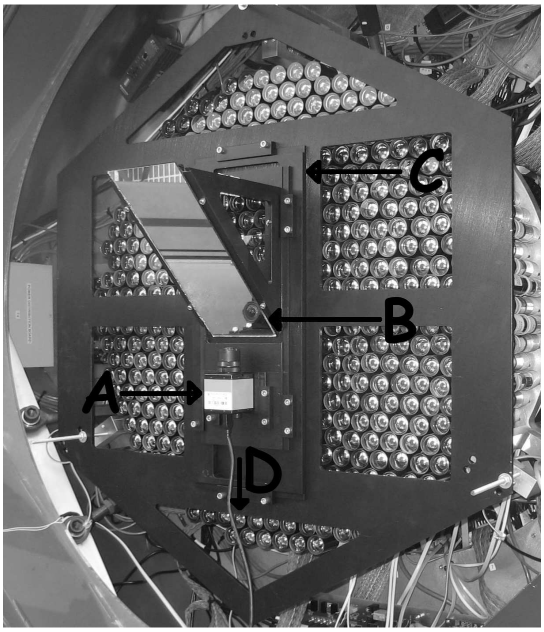
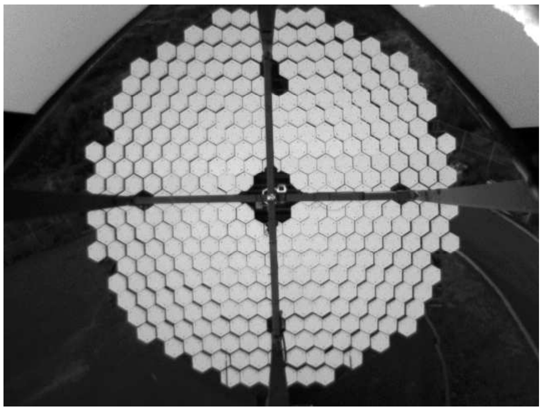
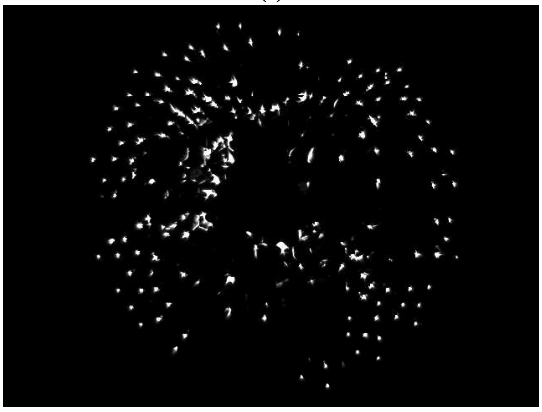


Fig. 2. A photograph of the alignment apparatus mounted on one of the VERITAS cameras. Arrow *A* indicates the CCD camera; *B*, the 45 degree mirror; *C*, the x-y positional stage and *D* the wire connecting to the data acquisition laptop (out of shot).



(a)



(b)

Fig. 3. Images, take by the CCD camera, of one of the VERITAS reflectors during the day (a) and at night, while pointing at a star (b). The bright spots in image (b) are caused by starlight reflecting off well-aligned facets while the dark regions indicate poorly-aligned facets.

then made to perform a raster scan around the position of the star. This has the effect of moving the image of the star across the CCD camera. At each point in the raster scan the CCD camera records how much starlight each facet is contributing to the image. Well-aligned facets will contribute their maximum amount of light when the telescope is pointing directly at the star. Misaligned facets will contribute their maximum amount of light when the angle between the star and the telescope pointing direction is twice the misalignment angle of the facet (see Figure 1). Performing a scan of this type allows for the determination of the misalignment angle, and therefore the required adjustments, for every facet of the telescope.

A photograph of the apparatus used to implement this method is shown in Figure 2. The main components of the apparatus are:

- a mounting plate
- an x-y positional stage
- a 45-degree mirror
- a CCD camera with wide-angle lens
- a laptop computer

The mounting plate and x-y positional stage are made from anodised aluminium. They provide a sturdy base for the CCD camera, allowing it to be mounted on the optic axis of the telescope, directly in front of the VERITAS PMT camera. The 45 degree mirror is positioned such that the virtual image of the CCD camera is placed at the focal plane of the reflector. The CCD camera is an *Imaging Source* DMK 21BF04 camera with a 1/4 inch 640x480 monochrome CCD and a firewire interface. The lens is an *Imaging Source* H0514-MP lens with a 5mm focal length. Image acquisition software runs on a *Dell* Inspiron laptop which is connected to the CCD camera and, via an ethernet cable, to the telescope tracking computer. Images of the telescope reflector taken by the CCD camera are displayed in Figure 3.

III. Initial test

This alignment system was first used on one of the VERITAS telescopes in April 2009. VERITAS Telescope 2, which had undergone the most facet replacements over the last year and thus had the worst Point Spread Function (PSF) among the telescopes in the array, was chosen for the first test. A star of magnitude 2, which had a transit elevation of 68 degrees, was tracked over a two hour period. During this time the average elevation was 66.5 degrees. The telescope was made to raster scan over a square grid of 21x21 points, with a step size of 0.025 degrees. From these data a set of adjustments was calculated. Of the 345 facets mounted on the dish, 150 were deemed to require adjustment. The mirrors of the VERITAS telescope are mounted on the optical support structure via a triangular bracket with a threaded rod at each vertex, supporting a mounting gimbal and adjustable nut. Any misalignment of a particular facet can be corrected by turning two of the adjustable

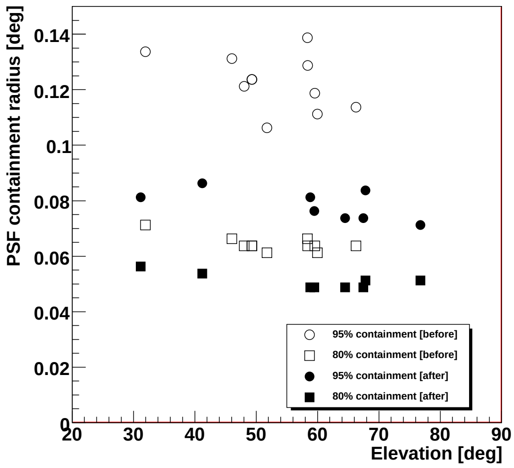


Fig. 4. A plot of the Point Spread Function of the VERITAS telescope 2 before and after alignment with the raster system.

nuts on the mirror mount assembly. Adjustments were made to 120 of the mirrors with a wrench which had a circular index wheel attached to it, so that adjustments of 1/2,1/4,1/8 and 1/16 of a turn were easily applied. The 30 remaining mirrors were located at the very top of the dish and could not be accessed at the time of adjustment due to high winds. PSF measurements were made before and after the adjustments were implemented and are plotted in Figure 4. The 80% containment radius of the PSF at 66 degrees elevation decreased from 0.064 degrees to 0.049 degrees after the alignment, a 22% improvement. Further improvement is expected with the adjustment of the 30 remaining mirrors and an iteration of measurement and adjustment based on a raster scan undertaken with greater angular resolution.

IV. Discussion

The initial test of the *raster method* has proved successful. The raster scan was completed in two hours and the data categorising the mirror alignment have been shown to be both useful and accurate. The procedure has proved to be much easier to implement than the previous alignment method [6] and indeed more accurate. This initial test has not, however, investigated the limit of the precision which is possible. Further tests are scheduled in which we will perform raster scans with a smaller grid spacing. With the current system the density of sampling across the raster grid, and therefore the accuracy to which we can measure the alignment of the telescope, must be balanced against the amount of time it takes to perform the scan. The characterisation of the telescope alignment must be made while the telescope is tracking over a narrow elevation band (∼5 degrees) due to the deformation of the optical support structure caused by gravitational slump. In the next scheduled alignment test we will perform a raster with high granularity over a raster grid comparable to the size of the, now reduced, PSF image. To enable us to implement the mirror adjustments calculated from a high resolution raster scan we are developing a "geared" wrench with a ratio of four turns to one. This will allow us to reliably make adjustment as small as ∼0.009 degrees (corresponding to 1/32nd of a turn of the adjustable nut) to each mirror. Ray-tracing simulations with the commercial package, *FRED*, and an independent ray-tracing analysis suggest that a PSF with an 80% containment radius of 0.042 degrees should be attainable within the telescope specifications.

V. Conclusion

An alignment system based on the SCCAN method suggested by [5] has been built, and tested on one of the VERITAS telescopes. The system has performed very well in this initial test. Further investigations are scheduled.

VI. Acknowledgements

VERITAS is supported by grants from the US Department of Energy, the US National Science Foundation, and the Smithsonian Institution, by NSERC in Canada, by Science Foundation Ireland, and by STFC in the UK. We acknowledge the excellent work of the technical support staff at the FLWO and the collaborating institutions in the construction and operation of the instrument. The authors gratefully acknowledge the help of Ryan Irvin, Ken Gibbs, Stephen Fegan, Jack Musser, Jeremy Perkins, Stephanie Wissel, Victor Acciari, Gary Gillanders and Mark Lang.

References

[1] J. Holder *et al.* , *Status of the VERITAS Observatory*, Proceedings of the 4th International Meeting on High Energy Gamma-Ray Astronomy. AIP Conference Proceedings, Volume 1085, 2008, p. 657.
[2] J.A. Hinton, *The status of the H.E.S.S. project*, New Astron. (Rev). 48 (2004) 331.
[3] C. Baixeras *et al.* , *Commissioning and first tests of the MAGIC telescope*, Nucl. Instrum. Meth. A. 518 (2004) 188.
[4] E. Roache, R. Irvin, J.S. Perkins *et al.* , *Mirror Facets for the VERITAS Telescopes*, Proceedings of the 30th International Cosmic Ray Conference, Vol. 3, 2008, p. 1397.
[5] F. Arqueros, G. Ros, G.R. Elorza, D. García-Pinto, *A technique for the optical characterization of imaging air-Cherenkov telescopes*, Astroparticle Physics. 24 (2005) 137.
[6] J.A. Toner, V.A. Acciari, A. Cesarini *et al.* , *Bias Alignment of the VERITAS Telescopes*, Proceedings of the 30th International Cosmic Ray Conference, Vol. 3, 2008, p. 1401.