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Simulation Study of Mirror Panel Alignment of MACE Gamma Ray Telescope

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The light collector of the MACE (Major Atmospheric Cherenkov Experiment) gamma ray telescope will comprise 356 mirror panels each of about 1m^2 area. These panels, which will be coupled to the telescope space frame using a 3-point support, will have prealigned spherical mirror facets fixed on them. All the three supports will use spherical ball joints to allow for changes in the orientation of the panel by actuators fixed on two support points while the third forms a pivot. Various alignment strategies for the mirror panels have been evolved and simulated under different test conditions and an algorithm has been developed for distinguishing the individual mirror images of a distant light source or a bright star on the focal plane even when two or more images are partially or fully overlapping with each other. The algorithm is able to align the panels within ±20arc-sec in two iterations. The details of the overall alignment scheme and the simulation study are discussed in the paper.

1. Introduction

The MACE gamma ray telescope is a large 21 meter diameter Cherenkov imaging telescope proposed to be installed at the high altitude observatory site at Hanle (32.7^o N, 78.9^o E, 4200 asl) in the Ladakh region of north India. The reflector of the telescope having f/d~1, will be quasi-parabolic in shape with a total reflecting area of about 340m^2. The reflecting surface will comprise 356 mirror panels of size 984mm×984mm and these panels, which will be coupled to the telescope space frame using a 3-point support, will have prealigned spherical mirror facets fixed on them. 228 panels will have four 488mm×488mm square shaped spherical mirror facets and the remaining will have nine 323mm×323mm square shaped spherical mirrors facets. All the three supports will use spherical ball joints to allow for changes in the orientation of the panel by actuators fixed on two support points while the third forms a pivot.

2. Mirror Alignment Techniques

Two methods have been suggested for alignment of the mirror panels. In the first method known as star test method [1], the telescope is pointed towards a bright star whose image is focused on the focal plane. The analysis of this image is used for quantifying the alignment status of the mirror panels. Before alignment multiple images of the star are formed on the focal plane by the various mirror panels. At first the spots corresponding to the individual mirror panels need to be identified and then the panels are to be reoriented so that all the spots focus accurately at the focal point. A CCD camera located at the center of the reflector, which is used to acquire the image of the star on the focal plane, provides the required optical feedback. The major advantage of this technique is that it uses a natural point source of light at infinite distance, which is directly imaged on to the focal plane and the alignment can be performed and also tested at any required elevation, however this method cannot be used for the correction of misalignment due to structural bending of the booms or the space frame of the telescope during operation.

The second method is based on laser pointing [2]. In this technique, a laser is mounted on each panel and its beam is aligned to a particular point on the focal plane. The original target points of the laser beams are marked on the focal plane with reference to LEDs. If any panel gets misaligned then its laser spot will deviate from its original designated position. Thus, the error can be calculated and the panel is moved so that the laser spot once again targets to its original position. Here again a CCD camera located at the center of the reflector acquires the images of the laser beams and provides the required optical feedback. The major advantage of this technique is that alignment of the panels can be checked even while the telescope is in operation. Using IR lasers and IR LEDs, the alignment can be checked and performed during daytime also.

Owing to the large size of the MACE telescope there will always be errors in the initial mechanical alignment while placing the mirror panels on the reflector surface. Also, there will be mechanical tolerances in fixing the laser at any specified angle. Therefore the star test method serves as the first level check for the alignment accuracy. Error offsets in laser pointing are then calculated and stored for subsequent use by the algorithm.

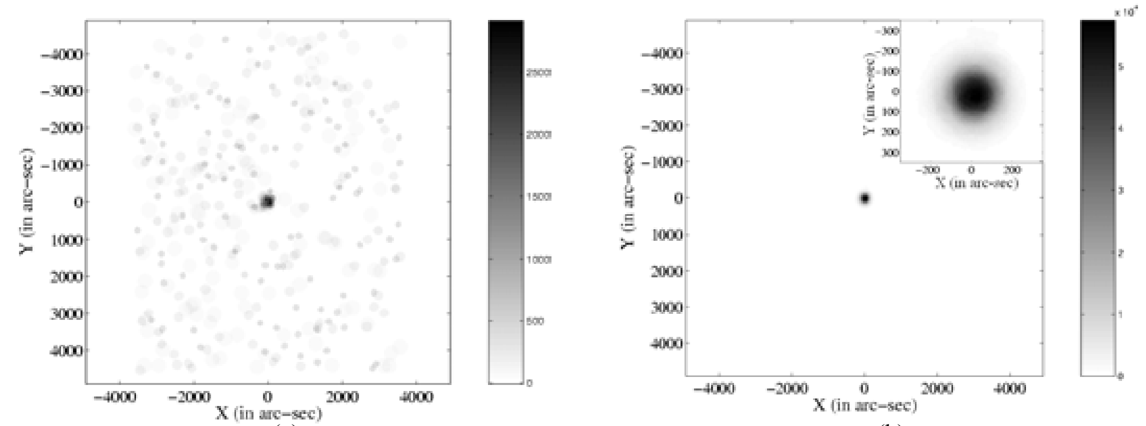
3. Development of Alignment Algorithm

Before alignment the image of the star would be scattered and there would be several light spots on the focal plane due to the individual mirror panels as shown in Fig. 1(a). Spots corresponding to the individual mirror panels are identified and the alignment of the panels is done in sequence. The actuator of a particular mirror panel is moved by a predetermined distance and CCD image of the star is taken before and after the movement. Subtracting these two images eliminates the spots generated by other mirror panels, images of secondary stars and inhomogeneous background illumination. Thus, the spots corresponding to the moved mirror panels are identified and their coordinates are calculated. The error in the spot position is calculated and converted into the movement parameters of the actuators of the panel. This sequence of operation is continued till all the panels are aligned.

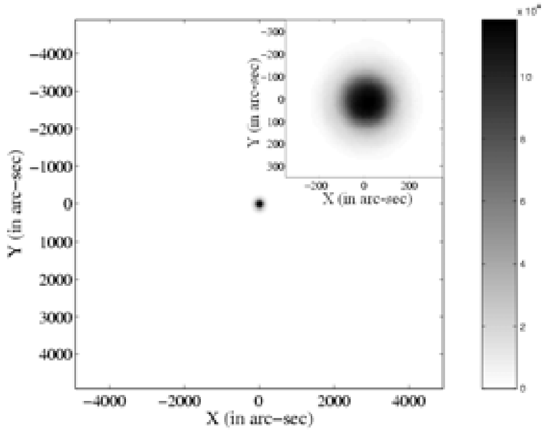
A number of complications arise in the implementation of the above-mentioned algorithm. Even after the subtraction of two frames many isolated pixels whose intensities are comparable to that of the star image are retained. This happens mainly due to the random background noise and the vibration of the structure. These isolated pixels lead to the erroneous calculation of the coordinates of the spot. Problem further worsens when some mirror panels are already aligned at the focal point, which forms what we will henceforth call the main spot. In this case, the change in the intensity of the main spot in two CCD images is comparable and in some cases even more than the intensity of an individual spot. The subtracted image thus retains many pixels from the main spot region, which makes the identification of the desired spot erroneous. Removal of the scattered residual pixels is simple as their intensities are quite small in comparison to the desired spot. It can be achieved in two steps: first by applying a Gaussian filter to the subtracted image and then setting up a certain threshold value to select the pixels. The amplitudes of the main spot region pixels are made zero to avoid their selection. Presence of the desired spot and its location in the main spot region is found by comparing the change in the value of centre of gravity (COG) of the main spot regions in two CCD images. Thus, the identification of all the individual spots can be worked out and their coordinates can be calculated.

4. Simulations and Results

Spot sizes produced by each mirror panel are different with panels located in the interior region of the reflector generating smaller spot size than the mirror panels located in the peripheral region. For simulation purposes, we have divided the reflector into 3 different zones: (a) Interior zone, which contains108 mirror panels. The value of r_{95} (equivalent radius within which 95% of the total intensity of the spot lies) is taken to be 60arc-sec. (b) Middle zone, which contains 120 mirror panels with r_{95}=100arc-sec, and (c) Exterior zone,



(a) (b)



(c)

Figure 1. Image of the star at the focal plane of the telescope: (a) Before alignment; (b) After 1st iteration; (c) Final image after 2nd iteration.

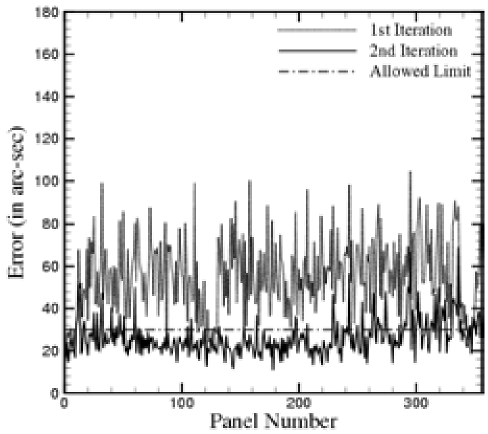


Figure 2. Mean errors in the different panels after 1st and 2nd iterations.

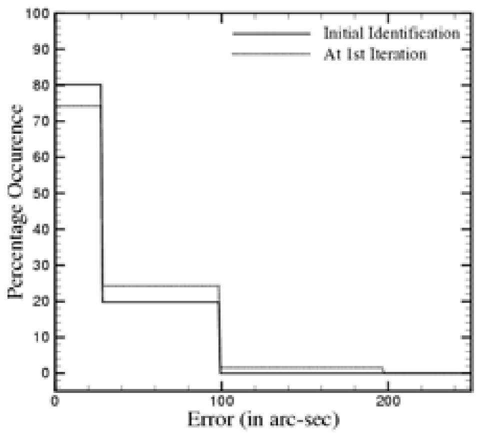


Figure 3. Percentage distribution of errors in coordinate calculation.

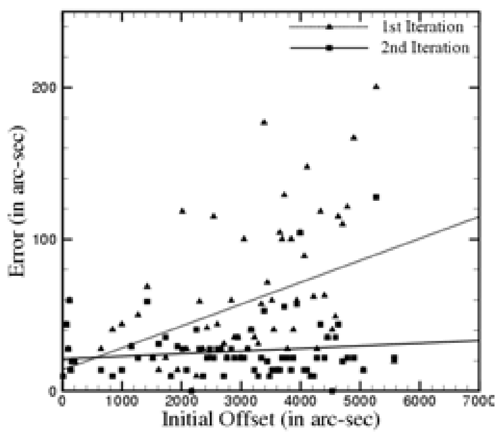


Figure 4. Variation of error after 1st and 2nd iteration with respect to the initial offset.

which contains 128 mirror panels with r_{95}=175arc-sec. Owing to the vibration of the structure, spots are assumed to be elliptical in shape and are larger than the base values mentioned above. Amplitude of vibration is assumed to be ± 40arc-sec. The alignment of the mirror panels is limited by the CCD resolution, stepper motor step size, mechanics of the facet support and the alignment algorithm. We target to align all the mirror panels within an accuracy of ±20arc-sec. If the displacement required to bring a spot to the focal point is more than 1000arc-sec, then the error due to the stepper motor is modeled to be a Gaussian of zero mean and standard deviation of 2% of the displacement. Otherwise, it is taken to be within ±20arc-sec. Signal to noise ratio varies from ~25dB to ~45dB for different spots depending on their sizes.

Spots are randomly distributed over the focal plane of size 1m×1m and the alignment algorithm is run. Results are calculated taking the data from 10 runs of the algorithm. Fig. 1 (a), (b) and (c) show the images of the star before alignment, after 1^{st} and after 2^{nd} iterations respectively. The radius, r_{95} of the final image is 206arc-sec. Fig. 2 shows the mean errors in aligning the panels after 1^{st} and 2^{nd} iterations where most of the panels are aligned to better than the error limit of 30arc-sec in 2 iterations. Variation of some important parameters in 2 iterations is depicted in Table 1. Fig. 3 shows the percentage distribution of the errors in the spot coordinate calculations during their initial identification and after 1^{st} iteration. Fig. 4 depicts the variation of error in alignment after 1^{st} and 2^{nd} iteration with respect to the initial offset value. Lines are drawn to fit the data linearly. As expected, the error in alignment increases with the increase in the initial offset and the variation is almost flat after 2^{nd} iteration.

Table 1. Some parameters at 1^{st} and 2^{nd} iterations

Parameters	**1^{st} Iteration**	**2^{nd} Iteration**
Radius (r_{60})	108arc-sec	98arc-sec
Radius (r_{95})	206arc-sec	206arc-sec
Panels with error (30-100arc-sec)	93%	23%
Panels with error (>100arc-sec)	0.5%	0%
Maximum alignment error	105arc-sec	70arc-sec

5. Conclusions

We have discussed the performance of an algorithm for aligning the mirror panels of the MACE telescope. The algorithm is able to detect the individual spots in the case of partial or full overlaps of spots in the same frame as well as in different frames of the images. The algorithm is able to detect and align all the mirror panels well within the telescope pixel resolution in 2 iterations.

6. Acknowledgements

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References

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[2] M. Garczarczyk et al., 28th ICRC, pp. 2935-2938, (2003).