ABSOLUTE TILT RECOVERY FROM LGSs: A CASE STUDY

A. Baruffolo, J. Farinato and R. Ragazzoni

Astronomical Observatory of Padova, vicolo Osservatorio 5, I-35122 Padova, Italy

Telescopio Nazionale Galileo, riv. Tiso Camposampiero 28, I-35122 Padova, Italy

ABSTRACT

VLT is taken as a case study for the tilt retrieving scheme from a Laser Guide Star using the auxiliary telescopes technique. Assuming that the auxiliary apertures can be moved anywhere on the set of rails surrounding the four VLT units, the corresponding patch on the sky useful to find out a suitable Natural Guide Star for tracking purposes is evaluated. This is accomplished taking into account both the thickness of the Sodium layer and the isoplanatic patch size that one can reasonably expect under good seeing conditions at the telescope site.

It is shown that the useful patch area to be looked for NGSs rotates and changes in shape in the sky during the observation of a single target. The sky coverages estimated for two cases are given, this allows to trace some preliminary conclusions on the feasibility of such tilt retrieving scheme.

Keywords: laser guide star, tilt recovery techniques, sky coverage

1. INTRODUCTION

Laser Guide Star (LGS) Adaptive Optics telescopes suffer from both conical anisoplanatism and lack of the absolute tip–tilt knowledge. These two problems reduce potentially both the maximum achievable Strehl and the sky coverage.

In the recent years several techniques have been proposed both for conical anisoplanatism removal and absolute tip–tilt retrieval. In this paper we discuss our first results obtained from a detailed calculation of sky coverage for the specific case of the VLT, assuming the adoption of the REM95 technique. We explore two situations, where the TF907 technique has been adopted for the conical anisoplanatism removal, or not. We introduce, in this way, a global approach to the problem of full–sky diffraction–limited imaging for 8m class telescopes.

2. THE VLT CASE

Several 8m class telescopes are built in a way to offer some potential interferometric capabilities. Interferometric capabilities from the two Kecks or from the two mirrors of the LBT are based upon a single baseline. In addition, Keck baseline is fixed on the ground so that Earth rotation allows for some extension of the (u, v) plane coverage. In the LBT case, on the other hand, being the telescope mounted on an altazimutal mount, the parallactic angle of an observed target change with time, so that a symmetric exploration of the (u, v) plane can be obtained. VLT is, in a sense, an unique case, because it comprises four 8m class telescopes placed in a non redundant configuration. Even from this very simplified analysis it is clear that VLT is the telescope array that can benefits more from the adoption of auxiliary telescopes to extend the (u, v) coverage. Moreover these can be relocated using a set of rails. While we are aware that these telescopes are supposed to work in an interferometric way only in some well specified positions on the grid of rails around the VLT units, we suppose in the following that they can act as tip–tilt estimators in any position on the rail. We are confident that this is not of unsurmountable difficulty and that this can turn out to be very effective. In the following we assume that the REM95 approach, in the single LGS case, is adopted. In this way only one auxiliary telescope is required, provided that a properly pulsed laser is used to fire the LGS used to sense the tip–tilt.
Figure 1. A pictorial representation of how a track is projected through the useful portion of an LGS on the sky; on the right the whole assembly of the several VLTI track projections is shown.

3. GEOMETRY OF THE PROBLEM

Assuming the LGS as a single point source located at a finite height, a single point on the ground individuates uniquely a point in the sky. The offset of this point with respect to the science target (where the LGS is fired) changes with time because of parallactic angle evolution and because the distance of the LGS beacon from the observer changes with time. In fact the Sodium layer altitude is fixed but, depending upon the elevation of the observed target, the true distance changes with time. This approach is exemplified and treated in some detail elsewhere. When a finite extension of the Sodium layer is taken into account a single ground point will translate into a well defined angular segment into the sky. Unless the ground point coincides with the LGS fire station, this segment will never collapse into a single point.

A further extension can be made allowing the ground–point to move along a ground segment. It is easy to see, in fact, that in this case the combination of each position of the auxiliary telescope on the ground segment, together with the LGS extension, will translates into a parallelogram projected on the sky (see also Fig. 1).

Occasionally this parallelogram will degenerate into a single segment (with a longer length, however, than the single–point case). In addition one should mention that while the parallelogram defines correctly the region of the sky where one auxiliary telescope free to move along the ground segment can find out a suitable reference star, two stars in these regions cannot be observed at the same time in the foreground of the LGS. These require two auxiliary telescopes on the same rail, unless the two stars are found within a single projection of the LGS extension.

These last considerations that can be useful for an in–deep analysis of the operational aspects of the absolute tip–tilt recovery, are not used in the following of the paper where we evaluate the detailed sky coverage for several patches in the galactic coordinate system.

4. SINGLE VS. MULTIPLE LGS

High Strehls can be obtained at visible wavelengths only through the removal of the conical anisoplanatism. The adoption of multiple Sodium LGSs, although not the only way to correct conical anisoplanatism, is one of the more
promising techniques to solve this crucial problem. Moreover it has been shown\textsuperscript{27} that the knowledge offered by this technique allow to correct for the conical anisokinetism\textsuperscript{28,29} also.

We distinguish in the following the two cases of a single LGS fired just toward the science target (we refer to this as to the single LGS case) or assuming to fire a few LGSs in a suitable circle around the science target. We used the figures quoted in the TF90 paper. We do not make any speculation, here, on the possibility to change the radial configuration to deal with a further sky coverage of the REM95 technique in the VLT case.

Here we wish to point out that there is no any a priori requirement on the position angle of the multiple LGSs constellation, provided that the radial geometry is consistent with the observation of the preferred science target. In our specific case this translates into the possibility to freely rotate the LGSs constellation around the line of sight of the main telescope (see Fig. 2). It is to be recalled, in addition, that the TF90 technique requires, from an operational point of view, some degrees of freedom in the firing mechanism or in the wavefront sensing of the multiple LGSs. In fact the apparent rotation in the field of view of the main telescope of a LGSs constellation fixed with respect to an altazimutal telescope will be different with respect to the one of the science target. In other words our requirements is partly already included in the operational aspects of the TF90 approach. We refer to this second approach as to the multiple LGS case.

5. COMPUTING THE SKY COVERAGE

The whole sky was divided into 42 regions on the basis of the galactic longitude and latitude. Five of these regions never rise over 30 degrees of height when observed from Paranal, so that they were not considered in our computations.

For each of the remaining regions we choose at random a target within it and a sidereal time of observation, so that the height of the target above the horizon was greater than 30 degrees. The set of rails surrounding the VLT's
Unit Telescope 1 was then projected into the sky at the resulting azimuth and elevation, taking into account the height and thickness of the Sodium layer, assumed to be 90 km and 10 km respectively, as explained in section 3.

When we considered the case where a single LGS is employed, this area was then convolved with a circle of radius equal to the isoplanatic patch size, which we assumed to be 3.5'' (good seeing conditions at Paranal). In the case where multiple LGSs are employed, the convolution was performed using an annulus with radius equal to the separation in the sky of the LGSs forming the constellation, which we assumed to be 48'',7 and thickness equal to the isoplanatic patch size.

After the convolution, the area in the sky was obtained, where a NUS useful for retrieving the absolute tilt of the LGS can be searched for. The probability of finding at least one such star was then computed using star counts from the Bahcall and Soneira galaxy model.

In our computation we took $V = 14.5$ as the limiting magnitude for the NGS. This was computed following Eq. (4) of Marchetti and Ragazzoni, assuming a diameter of $D_a = 1.8$ m for the auxiliary telescopes, $D = 8$ m for the main telescope and $r_0 = 20$ cm.

The entire process was repeated 100 times for both cases (single and multiple LGSs), for each region of the sky the final figure for the sky coverage was taken as the average of the probabilities for each run.

We performed our computations on a PC, equipped with a 166 MHz Pentium processor; each loop required about 5 seconds to complete, so that the whole calculation took $\sim 5.5$ hours.

6. RESULTS

Final sky coverages computed as discussed in the preceeding section are reported in Figs. 3 and 4 respectively for the single and multiple LGSs cases. These are reported in galactic coordinates and one can easily recognize the galactic SCP Zone of Avoidance.
center and plane, where sky coverages are usually substantially larger than elsewhere. Moreover the avoidance zones where, from Antofagasta, no objects is higher than the threshold of 30 degrees we have adopted, are easily seen.

As expected, the multiple LGS case shows values substantially larger, approaching the practical full-sky capability in most of the observable sky. Because these sky coverage probabilities are computed using a Poissonian statistics it is to be mentioned that in most cases more than one reference star can be used to recover the absolute tip-tilt. This translates into a larger flexibility in the usage of the auxiliary telescopes allowing, for instance, to use more than one VLT unit for full adaptive optics correction in the same or different directions.

**7. CONCLUSIONS**

The results we obtained can be roughly summarized in the graphs shown in Fig. 5, where we grouped the galactic plane regions and the two galactic poles together. As mentioned elsewhere, a sky coverage larger than 30% can be considered as whole sky capability. This translates into the statement that multiple LGS coupled with the REM95 technique in the VLT case allows to reach easily such a goal. With a single LGS this goal is reached in the galactic plane, but still results one order of magnitude better than the ones offered by Double Adaptive Optics are obtained at the galactic poles.

We are currently investigating further details related to this problem. For instance the calculations carried out in this paper refer to a classical observational approach where a specific object into the sky is to be observed at some specific instant. If one allows to shift observations in the right window during the night sky coverages can be further extended. Of course, in this last case, a further problem relating to the length of the achievable exposure will arise and will be the subject of a forthcoming paper.
Figure 5. An executive summary of the overall results of this paper.

REFERENCES


