Pointing and tracking results of the VST telescope

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ABSTRACT

The VLT Survey Telescope (VST) is the latest telescope installed at ESO’s Paranal Observatory in northern Chile. The exceptional quality of this site imposes tight requirements on the telescope performance in terms of pointing modeling and tracking. This paper describes the control strategy and the results obtained during the commissioning of the telescope.

Keywords: Telescope, Pointing, Tracking

1. INTRODUCTION

The VST [1]-[13] axes control loop commissioning activity had a good heritage from the work performed in Italy before the shipment of the telescope to Chile. This preparatory work allowed to proceed very smoothly during the telescope commissioning, with no real show-stoppers. Also the pointing model and autoguiding, which had never been tested before going to Chile, were successfully tuned.

The main goal of the telescope tracking is a stable image on the detector. This can be accomplished only by the combination of good pointing, servo and guiding performance. These three systems, whose names are sometimes confused each other, cooperate to the same result in different and complementary ways. The servo control system is designed to minimize the difference between the desired position and the encoder feedback. But even if this task is perfectly accomplished, still the image can significantly drift on the detector along the time. This happens because the encoders do not measure the orientation of the beam and the telescope mounts cannot be ideal, therefore the ultimate feedback shall be the movement of the image on the detector. The discrepancies are due to imperfections and deformations of the mechanical construction: typical errors are the non-exact alignment of the axes, the deformation of the telescope structure, the non-perpendicularity of the axes, the zero point offsets. These imperfections are taken into account in the pointing model, which is embedded in the generation of the reference positions for the axes servo control. Therefore the pointing model does not improve just the pointing itself, as it is sometimes believed, but also contributes to stabilize the image on the detector during tracking, removing most of the star drift. The residual drift is then removed by the auto-guiding system, using an outer control loop where the controlled variable is the position of the star on the CCD.

In the VST, both azimuth and altitude axes are equipped with four motors controlled in pairs, applying a constant preload torque bias that prevents backlash problems at almost zero speeds. The same solution (but using only two motors) is used for the rotator axis, which continuously corrects for the orientation of the instrument on the sky, because of the alt-azimuthal mount. The position feedback is provided by high quality glass disc encoders, customized for astronomical telescopes by the Heidenhain GmbH. The encoders are incremental, but using their distance-coded reference marks they also allow the determination of the absolute position during the initialization phase. The velocity feedback is provided by differentiating the encoder signal. Two nested control loops (position and speed) are implemented in order to provide a high quality pointing and tracking. The controllers have a variable structure to self-adapt to the different needs during the quite different phases of slewing and tracking.

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2. AXES SERVO CONTROL

The servo control activities had started well before the commissioning of the telescope. Control simulations had been done during the design phase [2][3], the hardware had been completed [4], the transfer functions of the axes had been identified and some preliminary tests had been done in Italy before the shipping to Chile [5].

Nevertheless, during the telescope commissioning the servo control has to demonstrate to maintain an optimal level of performance in any possible condition. Therefore, it is necessary to perform a complete set of tests, spanning all the different conditions for axes positions and speeds. A predetermined set of object coordinates was used to simulate a complete coverage of the sky, including critical conditions as the meridian crossing. This test case was always the same, allowing a direct comparison between data collected in different conditions, with the following variables:

- speed controller structure
- position controller structure
Figure 2. Altitude tracking map results. Figure 3. Example of altitude error evolution against time (up) and axis position (down) during a 3 minutes tracking test. The altitude speed was $v=-12''/s$, while $e=0.02''$ was the RMS servo error.

- wind speed
- ventilation doors open/closed
- wind-screen position

Data were collected considering the position errors in terms of deviation between reference coordinates and encoder values. Paranal is sometimes a windy site, where the environmental requirements set to $v=18m/s$ the maximum wind speed for the operations. During some nights with wind speeds around the maximum limit, the robustness of the system against the external wind disturbance was verified. Provided that the ventilation doors are closed and the windscreen is set to its upper position, the telescope servo system has proved to be unaffected by the wind disturbance, obtaining identical results with respect to the same test executed with no wind (enclosure closed).

Figure 2, Figure 4 and Figure 6 show the results of the test in terms of RMS errors, respectively for altitude, azimuth and rotator; the arrows point toward the motion direction, demonstrating the performance are the same in the two directions. A direct comparison show the rotator has the largest servo error, while the azimuth and altitude ones are comparable. The difference between azimuth and altitude is caused by the different speed ranges of the two axes: the maximum altitude speed at the latitude of Paranal is only about $13''/s$, while on the contrary the maximum azimuth speed becomes much larger near the blind spot. In most of the cases the azimuth travels faster than altitude and consequently the trajectory is followed with a little loss of accuracy. Nevertheless, the effect of the azimuth error on the image is lessened by the $\cos(\text{alt})$ factor, especially near the zenith.

The rotator speed range is also wide and the speed is again typically larger than the altitude velocity. Anyway, although the rotator servo error is the largest of the three, it is still always more than one order of magnitude better than needed, because the effect of the rotation error on the image quality is proportional to the image scale and to the physical distance from the centre of rotation. The VST detector is the OmegaCAM [14][15] square mosaic of CCDs, of about $24cm$ side: although it is much larger than the detectors of the traditional telescopes, still the maximum error is $e_M=0.01e_{\text{ROT}}$, where $e_M$ is the effect on the image corner and $e_{\text{ROT}}$ is the servo error. Therefore the tolerable rotator error is two order of magnitudes greater than for altitude and azimuth, and the servo requirements are consequently relaxed.
Figure 4. Azimuth tracking map results.

Figure 5. Example of azimuth error evolution against time (up) and axis position (down) during a 3 minutes tracking test. The altitude speed was \(v=28''/s\), while \(e=0.04''\) was the RMS servo error.

Figure 6. Rotator tracking map results.

Figure 7. Example of rotator error evolution against time (up) and axis position (down) during a 3 minutes tracking test. The rotator speed was \(v=23''/s\), while \(e=0.1''\) was the RMS servo error.

Figure 3, Figure 5 and Figure 7 show the position errors during a typical three minutes tracking data collection, with peak to peak values, respectively for altitude, azimuth and the rotator. Comparing the commissioning results with the data collected during the preliminary tests in Italy [5], a significant improvement is visible. The reasons are the new accurate setting of the controllers during commissioning, and the mechanical maintenance on some components, as the rotator bearing which had presented friction problems at earlier stages in Italy.
3. POINTING MODEL

The VST tracking software adopts an analytical pointing model based on TPOINT™ software, as most of the modern medium and large telescopes, which corrects the mechanical deviations from the ideal telescope. The parameters are calibrated by a set of pointing error measurements, collected in all the possible sky positions. An automatic procedure allowed to complete the acquisition in a reasonably short time (e.g. about one hour for 40 stars). Although the measurement is absolute, the quality of the results is incremental: starting from a bad model, the errors are large and the final fit will probably be inaccurate. On the contrary, starting from a decent model allows to improve the precision of the results. Therefore the building of the model is an incremental process that has always involved several steps, anytime the configuration of the telescope has been changed, e.g. for alignment purposes.

The TPOINT™ software allows to fit many parameters; the most commonly used are the six purely geometric terms that affect any alt-azimuth mount, and the tube flexures. Many other terms can be used to model cyclic errors but, although fitting more terms produces a better mathematical result, this does not necessarily correspond to a real physical effect, i.e. maybe the additional terms fit just the noise of the individual set of measurements and, once installed, they can even worsen the behavior of the telescope. Therefore, unless some of the unusual terms have been clearly identified, they have been removed from the fit.

Figure 8. Pointing model results.

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The quality of a pointing model is measured by the RMS value in arc seconds of the fit. This value is about 1” RMS for VST, with results during the telescope commissioning ranging typically between 0.8 and 1.2 arc seconds. The graphical representation of a pointing model building session is shown in Figure 8 for a set of 40 stars. These values are comparable with the other outstanding telescopes in Paranal (e.g. see [16]).

Once it is calibrated, the pointing model can be applied online to the telescope tracking software. The good quality of the telescope pointing helps the auto-guiding system, because the image remains quite stable during the typical VST exposure times, even without auto-guider. Therefore, for relatively short exposures, VST might in principle work without its guiding system.

4. AUTOGUIDING

The autoguider is based on a probe system hosted in the adapter-rotator (Figure 9); a pick-up mirror, that can positioned anywhere around the science object, deflects the light to a guiding camera composed by lenses and a technical CCD. The same light is split in two orthogonal arms by a dichroic that feeds also the wavefront sensor arm. The inclination of the pick-up mirror depends on the distance from the center, because of the field curvature. The guiding camera best focus is also dependent on the position in the field, and is adjusted with an additional servo mechanism. Therefore anytime a new guide star is selected, four servo mechanisms are activated in parallel: two for the positioning of the probe in polar coordinates, one for the angle of the pickup mirror, one for the focusing device. All the positions of the four motorized functions have been computed off-line using ZEMAX™ ray-tracing software and the results have been implemented in the telescope control software for the generation of the mechanisms reference positions; the optical theory was validated successfully on the sky.

The image on the CCD is stabilized with respect to the reference position, filtering the position error with a PII (proportional – double integral) controller [17]. With a star magnitude=12 the sensitivity of the system allows a frequency of the autoguiding loop of approximately 1Hz. Some results are shown in Figure 11, where the units are arc
seconds. The circles represent the RMS errors measured on the guide probe without autoguider and the squares are the RMS errors with active guiding; every star was tracked for 10 minutes. The positive effect of the autoguiding limits the image error within 0.1 arc seconds, as required from the specifications [18].

The OmegaCAM camera provides an alternative guiding system, that is without the scope of this paper.

Figure 10. Autoguiding and wavefront sensor panels working in parallel with the same star.

Figure 11. Effect of the autoguider. The movement of the image on the CCD in 10 minutes acquisition is reduced to an acceptable level by the corrections to the tracking axes. Units: arc seconds.
5. CONCLUSIONS

We have presented the pointing and tracking results obtained during the commissioning phase of the VST. After an accurate tuning, the pointing and tracking system has outperformed the specifications, reaching the level of performance of the other outstanding telescopes installed on the same platform.

REFERENCES