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LA SILLA OBSERVATORY

NTT Active Optics

User Manual

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1 INTRODUCTION

1.1 Purpose

This document provides the User Manual of the NTT Active Optics system. It also contains some informations concerning the maintenance of this system.

The audience is supposed to be mainly telescope operators but also support engineers and NTT astronomers.

In addition to the **Introduction** section, this manual contains the following sections:

- **System description:** Explains the working principle of the system
- **General considerations on operation:** Describes the constraints linked to the underlying physics of active optics
- **Standard operation**: Describes the typical use of AO system
- **Basic system maintenance:** Describes the tasks to be performed to maintain the system in optimum working conditions
- **Data logging:** Provides a description of the data automatically logged
- **Basic Troubleshooting:** Describes the most common errors

It is assumed that the reader has a good knowledge of UNIX, C-language, VxWorks, VLT Common SW, COBOL, ADA and Sepultura.

1.2 Scope

1.2.1 Current operation of the AO system

The operational requirements and project timescale (and budget) were such that it was out of the scope to develop a system that would be 100% automatic (the ultimate AO system would be the one that is automatically triggered at telescope start and stopped when night is over). Therefore, in its current state, the operation of the AO system still requires a bit of experience.
Acquiring this experience will allow the operator **to use at any time the full potential of AO system**. Fulfilling this objective not only requires a good knowledge of the AO commands but also a correct understanding of the underlying physics. This does not mean that the operators should be physicists but for example they should understand that correcting telescope aberrations amounting to 0.4 arcsec when outside seeing is 1.5 arcsec is not critical.

1.2.2 Level of operator involvement in AO operation

At low level, the system is complex as there are a lot of interactions with other sub-systems. Actually most of the complexity of the system has been hidden in the SW but the operator will still have to make operational decision concerning the AO operation. Therefore he will have to perform actions which can be logically classified as follow:

1. execution of routine commands

   The description of commands is given in section 5
2. decisions making regarding AO operations

   Example:

- Shall we start parallel mode with correction if the exposure is short and then the astronomer goes to another field ?
- How many aberrations measurements should be averaged before applying corrections ?

Many hints on how to use optimally the AO system are given in section 4. Also the interpretation of the results and the system specifications are given in the same section.

1.2.3 Normal activities performed on the AO system

The use of the AO system can be divided in three main activities as follow:

- the initialization of the system done as part of the setup (section 5)
- the routine use of the system during observations (section 5)
- maintenance of the AO system (section 6)

1.3 Reference Documents

The following documents contain additional information and are referenced in the text.

[1] Active Optics - A system for optimizing the optical quality and reducing the costs of large telescopes - R. Wilson- Journal of Modern Optics, 1987, Vol. 34, No. 4, 485-509

[2] Active Optics - Set-up and performance of the optics of the ESO New Technology Telescope (NTT) in the observatory - R. Wilson - Journal of Modern Optics, 1991, Vol. 38, No. 2, 219-243

[3] An analytical determination of the flexure of the 3.5 m primary - G. Schwesinger - Journal of Modern Optics, 1988, Vol. 35, No. 7, 1117-1149

[4] VLT-SPE-ESO-17230-1699, 1.0, 30/10/98 --- Active Optics - Algorithms for VLT and NTT

[5] N-MAN-ESO-108-062, 1.2, 22/11/96 --- nttm1 User Manual

[6] N-MAN-ESO-108-061, 1.2, 22/11/96 --- nttm1 Maintenance Manual

[7] N-TRE-PHG-REP/21, 1.0, 01/02/98 --- January 11 - 20 technical period at NTT

[8] N-PLA-ESO-108-063, 1.1, 26/05/96 --- NTT Upgrade - WC 8 - On-Line Test Plan

1.4 Abbreviation and Acronyms

The following abbreviations and acronyms are used in this document:

AO	Active Optics
cmm	Configuration Management Module
CCS	Central Control Software
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
LAN	Local Area Network
LCC	LCU Common Software
lccei	LCC Engineering User Interface
LCU	Local Control Unit
M1	NTT primary mirror

NTT	New Technology Telescope
SH	Shack Hartman
SPR	Software Problem Report
S/N	Signal over noise ratio
SW	Software
TBD	To Be Defined
TCS	Telescope Control Software
VLT	Very Large Telescope
WFS	Wave Front Sensor
WS	Workstation
ZD	Zenith Distance

1.5 Stylistic Conventions

The following styles are used:

bold - in the text, for commands, filenames, prefixes/suffixes as they have to be typed.

italic - in the text, for parts that have to be substituted with the real content before typing.

`teletype` - for examples.

<name> in the examples, for parts that have to be substituted with the real content before typing.

bold and *italic* are also used to highlight words.

1.6 Problem Reporting/Change Request

To:

- report a problem/error encountered using the software and/or the documentation,
- suggest changes in the software or documentation

fill an SPR-form[1] and send it with any other additional material that you think could be helpful, to ESO (e-mail vltsccm@eso.org).:

Your request will be checked-in the SPR data base and processed according to ESO change control procedure. The registration number will be communicated to you for further reference and you will be kept informed of the outcome of your SPR.

1. The utility `getTemplate` provides such form as editable file.

2 SYSTEM DESCRIPTION

This section provides an overview of the Active Optics system at the NTT. The fundamental principle is quite simple (See [1] for a more detailed description):

1. the slow varying optical aberrations affecting the telescope are either measured using a wavefront sensor (differential mode) or estimated using lookup tables (absolute mode).
2. the modifications of the telescope optical configuration (positions and forces) are computed.
3. the telescope optical configuration (primary and secondary mirrors) is corrected.

The different components of the system are the wavefront sensors, the workstation resident control software and the optical correction system.

2.1 Wavefront sensors

There is one wavefront sensor installed in each adapter. They are of the Shack Hartman type with a grid of 40 by 40 lenslets. The control of these wavefront sensors is done from two dedicated LCUs (lt5iaa, lt5iab) that performs the image acquisition and optical aberrations computation (process actServer). Then the coefficients of optical aberrations are passed to the WS where the AO control SW is running (process actconControl).

2.1.1 Detector characteristics

The characteristics of the wavefront sensor detector are:

- chip size: 592 * 578
- pixel size: 22 microns, 0.51arcsec on the sky
- saturation level: 4095 ADU
- serial number: tccd#21 (side A), tccd#23 (side B)

2.1.2 Control SW

Both LCUs controlling the wavefront sensors (lt5iaa, lt5iab) are loaded with SW module **act**. The only differences are some initialization parameters that are overloaded in the LCU database at boot time (file ntt/ENVIRONMENTS/lt5ia/dbl/DATABASE.db):

- orientation of the Shak-Hartman grid with respect to the detector (pitch and shift)
- number and position of traps inventoried in the chip

current SW version: act 1.18

2.1.3 Aberrations modes fitted

The aberrations modes fitted to the transverse aberrations are listed in the table below.For each mode, a coefficient and an angle (except for defocus and spherical aberration) are computed respectively in nm and deg. These values are converted in d80 (80% energy concentration diameter) which is expressed in arcsec. This allows to assess the relative importance of the aberrations affecting the telescope. The specification for the NTT is that each aberrations has a d80 lower than 0.08 arcsec except defocus for which the limit is set to 0.10 arcsec [2]

Aberrations name	Type	Symmetry	Order
tilt	Zernike	1	1
defocus	Zernike	0	2
decentering coma	Zernike	1	2
spherical aberration	Zernike	0	3
astigmatism	Zernike	2	1
triangular coma	Zernike	3	1
quadratic astigmatism	Zernike	4	1

Form of the Zernike polynomials:

$$W = k \times \rho^{m} \times \cos(n\Phi + \theta)$$

where **m** is the symmetry and **n** is the order of the polynomial, **k** the aberration modulus, ρ the radial distance on the pupil, ϕ the angle on the pupil and θ the aberration angle.

2.1.4 Indicators of sensing accuracy

2.1.4.1 Fitting residual

The fitting is done using a least square method (See [1]). An important parameter allowing to assess the correctness of the fit is the fitting residual given in arcsec. If the fitting residual is very large, this means that the set of aberrations modes used (7 in the case of the NTT) did not allow to reconstruct with good accuracy the wavefront. Some additional aberration modes would be necessary to reconstruct accurately the wavefront. These aberrations were very likely introduced by bad seeing or local air problem in the telescope (example: mirror seeing). This fitting residual is therefore a very good indicator for trusting or not the aberrations measured by the wavefront sensor. The following rule of thumb is used:

fitting residual > 0.18 coefficients of aberrations cannot be trusted

It should be noted that the best value ever recorded was 0.09 under exceptionally stable conditions.

2.1.4.2 Variations rms

Usually several measurements of the coefficients of wavefront aberrations are averaged to compute the necessary optical changes for correction. The **variations rms** is just the rms of the data averaged. There is one variations rms for each aberration mode and it is expressed in nm. This indicator evaluates directly the stability of the aberrations measured. This variations rms is usually smaller for large order aberrations and is typically between 100 to 200 nm. There is no limit set on these parameters as they proved to be quite stable, nevertheless they are displayed on the AO engineering interface for information.

2.2 Workstation control process

The control of the AO system is done at WS level (wt5tcs) by the process actconControl. The main tasks are to manage the interactions between AO sub-systems and to compute the optical configuration changes. Here is a list of sub-systems that interacts at some point with the AO activities:

- wavefront sensors (lt5iaa/lt5iab)
- Primary mirror (lt5m1)
- Secondary mirror (lt5m2)
- adapters (lt5ada/lt5adb)
- mode switching (WS process mswControl)

The SW running on the workstation is included in module **actcal** (computation of optical configuration changes), module **actcon** (management of interaction between sub-systems) and module **actgui** (graphical interfaces). The computation of force changes on the primary supports is done using a pre-defined modal calibration as explained in [1] and [3]. As for the computation of M2 position change, it also uses a pre-defined calibration. The exact conversion factors between aberrations measured in nm by the wavefront sensor and motion of the M2 unit in mm are given in document [4].

Current SW versions: actcal 1.50.1.1, actcon 1.55, actgui 1.3.1.3

2.3 Optics correction

The optical configuration is modified by moving the secondary mirror along 3 axis and modifying the forces applied by the 75 actuators supporting the primary mirror.

2.3.1 Primary mirror

2.3.1.1 Correction principle

The LCU lt5m1 controls the primary mirrors which means at low level two basic tasks:

- Measurement of the force exerted by each of the 75 actuators + 3 fixed points
- Control of the motors of the 75 actuators (switch ON/OFF and UP/DOWN).

Based on these two basic actions are built more complex tasks. The main task that is used for AO operations is the force setting task (command SETM1 at the LCU level). This commands requires the following parameters:

- a flag indicating if the correction is absolute or differential (DIFF or ABS)
- 75 values corresponding to the requested forces (or force variations) on the 75 actuators

This setting is done in parallel mode which means that all the actuator motors are started at the same time and moved during a length of time proportional to the magnitude of the force variation

needed. When the last motor has been stopped, the forces exerted by the 75 actuators are measured again and compared to the target force. The precision of the setting is quantified by computing the average of the absolute value of the difference between target force and current force. If this figure is below the specification (currently 1.5 N), the force setting is considered finished. In the opposite case, another iteration is performed. This is valid until 3 iterations have already been performed, then the force setting is considered finished anyway.
Many others commands are available on lt5m1 especially for maintenance purposes, their exact syntax and meaning is given in document [5].

2.3.1.2 Indicators of setting accuracy

Once the force setting is completed, numerous parameters are computed to assess the efficiency of the setting. The most relevant are the following:

- the average of the absolute force errors on the 75 supports
- the number of iterations performed
- The duration of the operation

The specification on the first parameter is a value lower or equal to 1.5 N knowing that a maximum of 3 iterations are allowed. This limitation to 3 iterations has been decided after the test of the new M1 control SW installed after Big Bang [8]. If the average of the absolute force errors is larger than 1.5 N, the most likely explanations are the following:

- the telescope is at a very large zenith distance and force correction is only partial.
- one or several actuators have a problem, check which one(s) by looking at M1 setting log file (See section 5.2).

2.3.1.3 Control SW

The control SW of the primary mirror is loaded in LCU lt5m1. The module containing the control SW is called nttm1.

Current SW version: nttm1 1.27

2.3.2 Secondary mirror

2.3.2.1 Correction principle

The secondary mirror can be moved along three directions. Along the telescope axis (conventionally called Z axis), this is a pure translation while in the perpendicular plane, the motions (X and Y directions) are rotations along the center of curvature of the mirror. This has been done on purpose so that any motion performed along X or Y axis does not affect the telescope pointing. The motion along Z axis is used to correct for defocus while motions along X and Y axis are used for coma correction.

2.3.2.2 Indicators of setting accuracy

No indicator is available for the M2. If the setting is done without error, it means that the positions requested have been reached within the specification of 0.001 mm in position and 50 sec in time.

2.3.2.3 Control SW

The control SW is loaded on LCU lt5m2.

Current SW version: nttm2 1.13

3 General considerations on operations

3.1 General recommendations

3.1.1 The 2 modes of AO system

The user of the AO system should be aware that the system can be used in two distinct modes. The AO system aims at optimizing the optical configuration of the telescope and this can be done either in **differential** mode or in **absolute** mode.

The differential mode relies on the information given by the wavefront sensor. It is called differential because the changes on the optical configuration (forces or positions) are done relatively to the current state.

The absolute mode relies on a model for M1 cell support forces and M2 positions which depends on telescope altitude and telescope tube temperature. It is called absolute as the forces (on M1) and positions (on M2) are set absolutely (and do not depend on current state).

The advantage of the differential mode is its precision. Indeed the statistical analysis of the aberrations measured by the wavefront sensor model shows that the behavior of the telescope is not fully repeatable. This means that the absolute mode model accuracy is not as good as the one of the wavefront sensor.

The disadvantages of the differential mode are

- the extra time that is takes to perform the wavefront sensing
- the need for a suitable sensing star
- the need of acceptable meteorological conditions

This last argument is lessened by the fact that optical optimization is not that critical at the NTT when the seeing conditions are not good.

During night time, the differential mode is the default mode.
In the facts, the absolute mode is used in the following cases:

- to initialize the telescope as part of the startup (e.g. during day time)
- to optimize the optical performance of the telescope when the wavefront sensor cannot be operated (no suitable guide star, bad seeing, ...)

3.1.2 When should the AO system be used ?

The AO system plays a fundamental role in the concept of the NTT. One of the main requirement is to obtain image quality as close as possible to outside conditions. This is only possible if optical aberrations introduced by the telescope itself are kept to a minimum. This can only be reached if these aberrations are measured and corrected via the AO system. As some of these aberrations are position dependent (flexure, thermal effects), the correction of aberration has to be done as often as possible. The default operation mode of the AO at the NTT is therefore as follow:

- at each preset to a new field, the AO should be used to optimize the telescope optics **before** starting observing (if not possible in differential mode, this should be done in absolute mode)
- then the AO should be run **during** observation. The system is foreseen so that this is transparent for the observer, this is the so-called parallel mode. This operation is only performed in differential mode. If this is not possible (bad weather conditions, no suitable

guide star), then AO operations are suspended. This means that the absolute mode of AO is currently never used in cyclic mode at the NTT.

One should be aware that the reduction of telescope aberrations is all the more important when the outside seeing is very good. On the other hand, when the outside seeing is poor, it is very likely that the degradation of image quality due to telescope aberrations are negligible.
Example:

Relative importance of telescope aberrations vs outside seeing

outside seeing (arcsec)	telescope contribution (arcsec)	effective image quality obtained (arcsec)
0.5	0.4	0.64
1.0	0.4	1.08
1.5	0.4	1.55

From this table, it is clear that it is critical to correct telescope aberrations when observing under 0.5 arcsec seeing while it is not really critical when observing under 1.5 arcsec seeing.

3.2 Wavefront sensor

3.2.1 Importance of the guide star

The wavefront sensor needs a star to assess the shape of the wavefront. As said before, the telescope pupil is re-imaged and the starlight goes through a grid of lenslets. Each sub-image formed is used to measure the local slope of the wavefront. To this end, the position of the sub-image is compared to the position of the image that is obtained when using a reference light located inside the adapter (that is supposed to deliver a perfectly plane wavefront). It takes about 400 sub-pupils to cover the entire telescope pupils. The wavefront is then reconstructed by fitting the discrete information obtained (the 400 slopes).
The star used for this purpose is the guide star as the wavefront sensing system should work while scientific observations are performed. A beamsplitter has been installed inside the adapter so that the guide star light is shared between autoguider detector and WFS detector. This double use means that there should be a good agreement between WFS and autoguider as far as guide star magnitude range is concerned:

- The guide star should not be too bright so that none of the detectors are saturated
- The guide star should not be too faint so that the S/N on both detectors is good enough

This has been done by defining properly the characteristics of the beamsplitter. The beamsplitter we use at the NTT sends 90% of the light to the wavefront sensor. The acceptable magnitude range for the guide star is then between 11 and 13.5

3.2.2 Averaging of results

After each SH exposure is taken, optical aberrations are computed. The SW allows to average the optical aberrations of a given number of individual exposures before computing the corrections to be applied on M1 and M2 mirrors. This possibility proves to be advantageous in different cases. An example is given in the next section.

3.2.3 SH exposure time

The Shack Hartmann is supposed to measure the optical aberrations affecting the telescope. As the incoming beam had to go through the atmosphere before entering the telescope and that atmosphere also introduces some optical aberrations, it is logical that the wavefront sensor measures the cumulated effect of atmosphere + telescope. As the aberrations introduced by the atmosphere are rapidly varying (from 1 to 1000 Hz), the active optics system cannot correct these aberrations. In order to get rid of those aberrations in the measuring process, the only solution is to take Shak Hartman exposure with a duration that is long enough so that the atmospheric aberrations are averaged out. At the NTT, the normal exposure time is 30 sec and it is considered that with such a value, the atmospherically induced aberrations are averaged out.
Nevertheless, there is a case when it is necessary to lower the exposure time. It happens when the guide star found is very bright and would saturate the SH CCD if exposing for 30 sec. In this case, it is possible to make shorter exposures (down to 5 sec) and then average a sequence of images.
Example:
Usually the corrections are computed after averaging 3 image analysis of 30 sec. If the star is too bright, it is possible to perform series of 9 image analysis of 10 sec each.

3.2.4 Aberrations measured

The Shack Hartmann is located inside the adapter which means that the aberrations measured by this device includes the atmosphere and the telescope (M1 + M2 + M3) but excludes the possible aberrations introduced by the optics located between the adapter and the scientific detector. In the case of SUSI2, it is quite simple as the instrument optics is quite simple (M4 flat mirror + filter) but for SOFI and EMMI, there are numerous pieces of optics involved. To assess the aberrations introduced by the instruments, the only technique currently available is the curvature sensing technique that relies on defocussed images taken directly on the scientific detector. Then the difference between aberrations measured by the SH and the curvature sensing technique yields the aberrations introduced by the instrument. These aberrations can be introduced in the AO SW via a table in the WS database and there are added to the aberrations measured by the SH at each analysis. Currently this table is set to 0.

3.2.5 Defocus measurement

The defocus measured by the wavefront sensor is theoretically the telescope defocus. This is actually a bit different as the SH is located after a focal reducer. Therefore it is important to adjust the focal reducer position in such a way that the image plane of the telescope corresponds to the object plane of the focal reducer. Practically it means that the reference unit (that supports the reference light) should be in the focus plane of the telescope. This can be done by tuning the reference position of the adapter trombone (one for each Nasmyth focus). At SW level, this parameter is included in the database:

adapter A	@lt5ada:PARAMS:DBNTTAD.focusOffset
adapter B	@lt5adb:PARAMS:DBNTTAD.focusOffset

Although the telescope focus should be the same for any instrument, this is not the case in practice (error in positioning of the scientific detector in the precise image plane compensated by a defocus in the telescope). Therefore the reference trombone position should be determined for each instrument. The determination method is as follow:

1. Set properly the instrument focus using usually a temperature dependent law (none for SUSI2)
2. Perform a through focus sequence and adjust accordingly the secondary mirror position
3. Perform a AO wavefront sensing and adjust the trombone reference position until you get a 0 defocus value
4. Perform another through focus sequence to make sure that the telescope focus is still correct. If not, iterate step 2 and 3

The setting of the database attribute for side A depends on which instrument is used. This should be done eventually automatically by the msw module but for now a work around has been implemented: when an instrument is selected in the TCS main panel, the corresponding database attribute (adapter B for EMMI and adapter A for both SUSI2 and SOFI) is set to the value defined for this very instrument (this value is **hard-coded in the definition of TCS main panel**). Also there is a manual command on the wa5tcs mouse menu that allows to set this database attribute depending on the instrument used. This command should be used only when the LCU is rebooted at some point to set properly the database attribute as after a reboot it is set to 0 by default. The values for each instruments are therefore **also hard-coded in the definition of the menu buttons for wa5tcs WS**. Any change of these values should be reflected at **BOTH** places.

IMPORTANT: The setting of the database attribute should not only be correct at the time of performing the image analysis on the sky but also when performing the reference image analysis (See section 4.4 '**Change of instrument**' for a precise description of actions to be taken when switching from one instrument to another).

For reference, the equivalences between M2 position, SH defocus measurement and trombone offset position are given:

- an offset of 0.05 mm on M2 will create a defocus of 1330 nm on the SH
- 2060 nm on the SH corresponds to a reference offset of 2 mm

Example:
The focus delivered by the image analyser is such that M2 has to be moved by +0.05 mm to have the right telescope focus with the EMMI instrument. +0.05 mm on the M2 corresponds to 1330 nm on the SH, which corresponds to a offset of 1.3 mm of reference trombone position. If the previous reference trombone position was 0, the new one should -1.3

3.2.6 Limitation to the use of the wavefront sensor

When performing infrared observations, the telescope is used in the so-called beam-switching mode. In this case, the telescope is moved back and forth and this means that the guide star moved out of the Shack-Hartmann detector. Currently the wavefront sensor is not used in such conditions but it is hoped that it will be possible to use the system with minor modifications in the near future.

3.3 Force setting

3.3.1 M1 force setting

The forces on the primary mirror can be modulated by two means:

1. via the spring installed on each actuator
   - The force exerted by the spring is constant whatever the telescope zenith distance is.
   - The force exerted by the spring cannot be changed automatically, it requires a manual intervention on the M1 support cell with a screwdriver
2. via the counterweight installed on each couterweight
   - The force exerted by the counterweight is astatic (e.g. proportional to the cosines of the zenith distance)
   - The force exerted by the counterweight can be modulated automatically and its position is computer controlled via motors.

The adjustment of the spring load on each actuator is an operation that is supposed to be done once for all. It is checked during regular maintenance operations (See chapter 6.3.4) that the force exerted by the spring is correct.
As for the counterweight force, it is actually used to modulate the force on the mirror and correct the aberrations detected by the wavefront sensor. As the force change is performed on the counterweight, it means that the force difference applied will change when the telescope moves in altitude and therefore will introduce some additional aberrations.

- This is one of the reason why the AO system should be used **obligatorily** at each field change.
- This is also another justification for the parallel mode of AO to be used (and computed corrections applied) as the telescope altitude is continuously changing when tracking.

3.3.2 Modes corrected

There are two general types of modes that can be corrected: the Zernike modes and the elastic modes. The Zernike modes have an optical justification while elastic modes have a mechanical justification. The Elastic modes are the free excitation mode of the mirror which means that they require less force compare to the Zernike modes for correction. Actually to each Zernike mode corresponds an elastic mode that provide an optical correction very similar but with required force much smaller. This property had to be used for the correction of the spherical aberration affecting the NTT. Indeed when the primary mirror was delivered, a large amount of spherical aberration was detected on the primary mirror. This aberration could be corrected using the springs on each actuator but would have required forces larger that the available range if corrected using Zernike modes. Therefore the correction has been performed using the elastic mode which reduced the force required by a factor 2 and therefore made it possible.

3.3.3 M1 force settling time

The M1 force settling time depends on the amplitude of aberration detected and therefore force change required. The usual force settling time is around 60 seconds. For each actuator, the length of time ΔT the motor has to be switched on is computed using the following formula:

I

$$\Delta T = \frac{\Delta F}{\frac{dF}{dt} \times \cos(ZD)}$$

where dF/dt is the so called temporal gain expressed in N/s and measured at zenith and ZD the zenith distance. Actually those temporal gains are defined in both directions for each actuators (increasing and decreasing forces) which means in the case of the NTT 150 different gains. These gains are measured experimentally typically once a month as part of the maintenance plan (See section

6.3.3). The dependence with zenith distance explains why the AO SW has to send regularly to the LCU lt5m1 the latest value of this parameter.

3.3.4 Aberrations corrected on primary mirror

The Zernike modes corrected on the primary mirror are the following:

- spherical aberration
- astigmatism
- triangular coma
- quadratic astigmatism

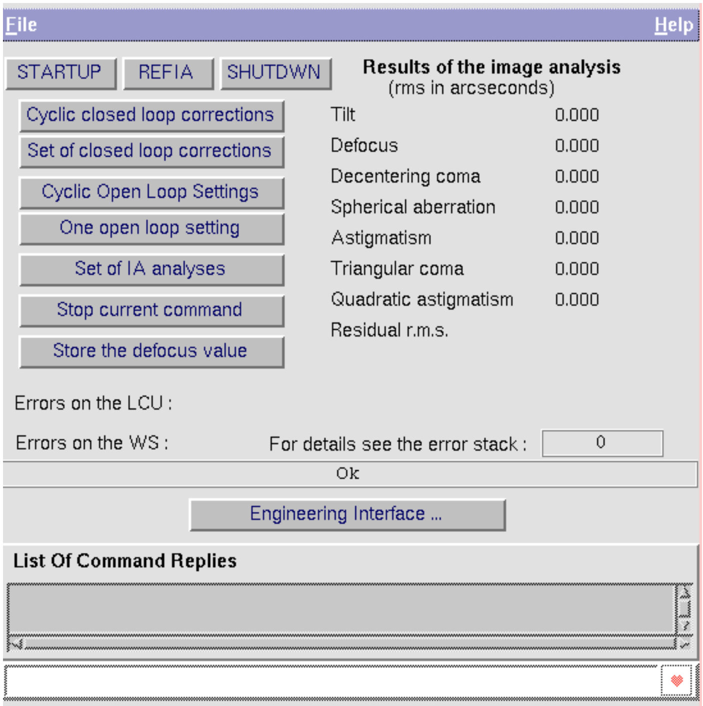
In the special case of spherical aberration, the correction is not only performed on the primary mirror but also on the secondary mirror. Indeed the correction of spherical aberration requires large amount of forces at the edge of the mirror and this limits the range of spherical aberration that can be corrected. Therefore the trick is to perform part of the correction by moving the secondary mirror along the focus axis.

4 Standard Operation

4.1 Graphical user interface

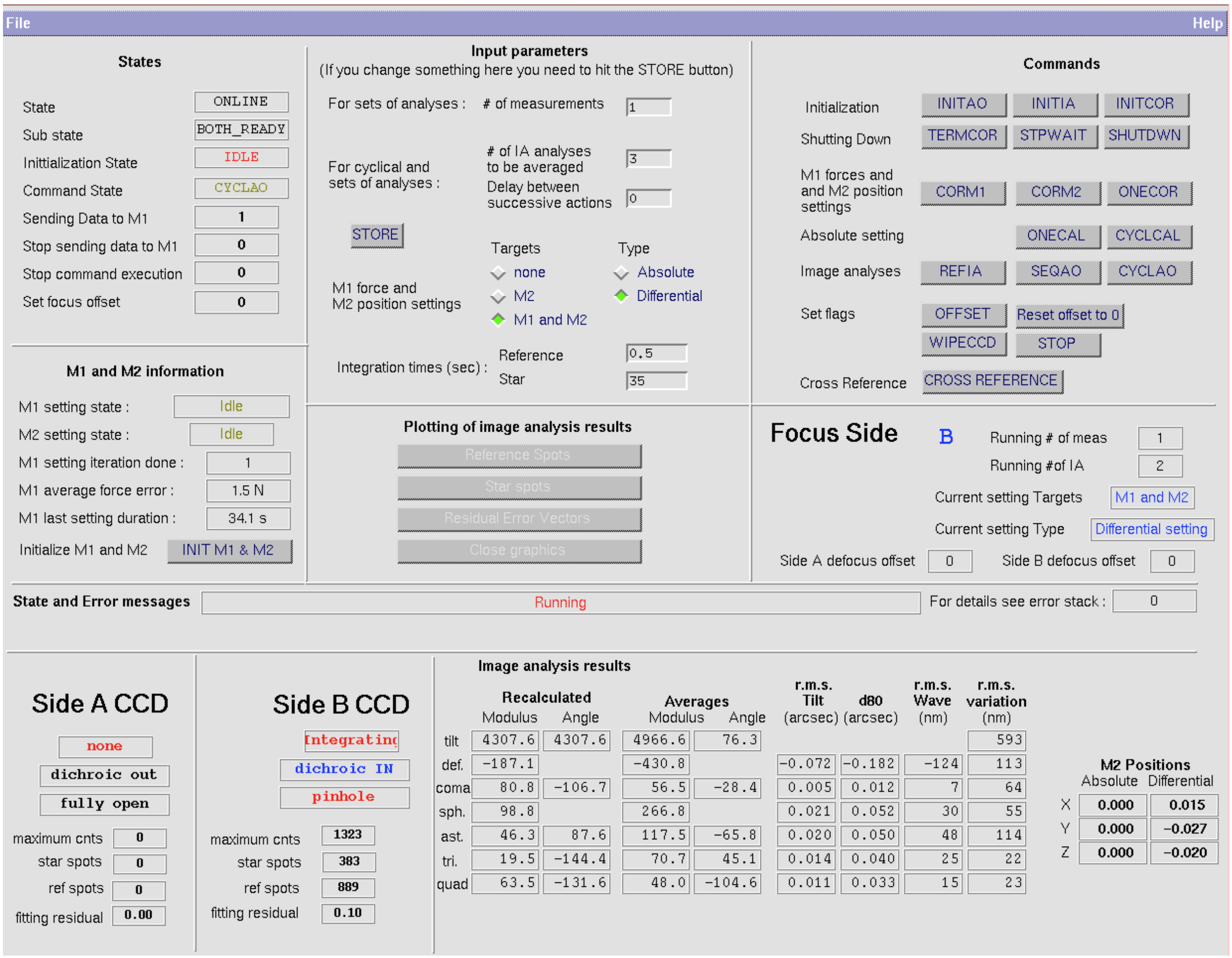
4.1.1 User panel

The AO system is operated from a graphical user interface from the **wt5tcs** workstation under account **tcs**. There are actually two panels: a so-called user panel containing the bare minimum of informations/commands (invoked by command **actconUser**) and a so-called engineering panel where detailed informations related to AO system is displayed. For historical reasons, operators prefer to use the engineering panel which anyway has to be started from the user panel.



The only command used on the panel is:
Engineering interface: it starts the AO engineering interface passing as a parameter the Nasmyth side currently used (either A or B).

4.1.2 Engineering panel



States area:

State	state of the actconControl process (should be ONLINE to use AO system)
Sub state	sub state of the actconControl process. It can have the following values: -> NONE_READY: SH detector is not initialized and no data sent to M1 -> IA_READY: SH detector initialized but no data sent to M1 -> COR_READY: data sent to M1 but SH detector not initialized -> BOTH_READY: SH initialized and data sent to M1
Initialization state	indicates name of initialization/stop command running -> should be IDLE to use AO system
Command state	indicates the name of the current running command if any
Sending Data to M1	Indicates if telescope ZD value is regularly sent to M1 -> 0 means that it is not done -> 1 means that it is done (should be the case when initialized)
Stop sending data to M1	Indicates if a command is running to stop sending telescope ZD to M1 -> 0 means that it is not the case -> 1 means that it is the case
Stop command execution	Indicates if a STOP flag is currently active
Set focus offset	Indicates if the focus offset flag is currently set -> it should be 0 except few cases (unknown focus filter offset)

Input parameters area:

*# of mea*surements	input for commands SEQAO
# of IA analyses to be av.	input for commands SEQAO and CYCLAO
delay between actions	input for commands SEQAO and CYCLAO
*STOR*E	button to press after **ANY** change in the input parameters
Targets	input which defines which optical element is corrected -> input for commands INIT M1&M2, CORM1, CORM2, ONECOR, ONECAL, CYCLCAL, SEQAO, CYCLAO
Type	input to define what is the type of correction to be applied -> input for commands CORM1, CORM2, ONECOR
Reference integ. time	exposure length in seconds of reference image analysis -> input for commands REFIA and CROSSREFERENCE
Star integ. time	exposure length in seconds of star image analysis -> input for commands SEQAO, CYCLAO

It is very important to note that these fields are only input fields. Each time one wants to change any of these values, the button STORE has to be pressed. This also means that the fact that a value is displayed in an input field does not mean that the database has been updated. Therefore when you start using the system, input the value you desire and press STORE button.

Commands area:

INITAO	INITAO send sequentially INITIA and INITCOR commands
INITIA	INITIA initializes communication between AO WS process and the wavefront sensor detector (triggers IA_READY)
INITCOR	INITCOR initializes communication between AO WS process and the primary mirror (sends value of telescope ZD, triggers COR_READY)
TERMCOR	TERMCOR terminates the communication between AO WS process and primary mirror (turns off 'sending data to M1').
STPWAIT	-> STPWAIT stops AO activities after current action is finished
SHUTDWN	-> SHUTDWN stops AO activities immediately
CORM1	perform the last computed correction in mode **Type** on M1 -> inputs: **Targets** and **Type**
CORM2	perform the last computed correction in mode **Type** on M2 -> inputs: **Targets** and **Type**
ONECOR	perform the last computed correction in mode **Type** on M1 + M2 -> inputs: **Targets** and **Type**
ONECAL	compute and perform an absolute correction -> inputs: **Targets**
CYCLCAL	compute and perform cyclical absolute corrections -> inputs: **Targets** and **delay between successive actions** This option is currently **not used** at the NTT.
REFIA	performs a reference image analysis -> input: **reference integration time**
SEQAO	execute SH exposures, compute corrections and apply them if requested -> inputs: **# of IA analyses, # of measurements, star integration time, targets** and **delay between successive actions**
CYCLAO	execute SH exposures cyclically, compute corrections and apply them if requested -> inputs: **# of IA analyses, star integration time, targets** and **delay between successive actions**
OFFSET	set focus offset flag Used only with SUSI2 when filter focus offset is unknown.

Reset offset to 0	set to 0 focus offset value for the Nasmyth side currently used
WIPECCD	send command WIPECCD to actconControl -> the SH detector is wiped
STOP	send command STOP to actconControl -> stop immediately execution of AO activities
CROSS REFERENCE	move GP to center and send command SEQIA "REF" to actconControl -> inputs: **# of IA analyses** and **reference integration time**

M1 and M2 information area:

M1 setting state	indicates current activity on primary mirror. Possible strings are: -> Idle, computing forces,1st Par. setting,2nd Par. setting, 3rd Par. setting Accuracy control
M2 setting state	indicates current activity on secondary mirror. Possible strings are: -> Idle, X moving, Y moving, Z moving
M1 setting iteration done	indicates the number of iterations done on the primary mirror during the last force setting (varies between 0 and 3)
M1 average force error	indicates the final force error on the M1 after the last force setting (specification is set to 1.5 N)
M1 last setting duration	indicates the duration of the last M1 force setting (in seconds)
INIT M1 & M2	Send command ONECAL to actconControl process

Focus Side area:

Running # of meas	indicates the index of the current aberrations measurement
Running # of IA	indicates the index of the current SH exposure
Current setting Targets	indicates the elements to be set for the next optical correction -> can be **None**, **M2** and **M1 and M2** (reflects the last **Targets** set with STORE)
Current setting Type	indicates the nature of the correction -> can be **Differential setting** or **Absolute setting** (reflects the last **Type** set with STORE)
Side A defocus offset	indicates the value of the internal focus offset for side A -> 0 unless correcting for filter offset
Side B defocus offset	indicates the value of the internal focus offset for side B -> 0 unless correcting for filter offset

Side A CCD/Side B CCD area:

Maximum cnts	maximum pixel value on the last SH detector frame
star spots	number of spots detected in the star Shak-Hartmann pattern
ref spots	number of spots detected in the reference Shak-Hartmann pattern
fitting residual	residual of the last aberration fitting

Image analysis results area:

Recalculated	aberration calculated in M1 reference frame for a single SH image
Averages	average of **# of IA analyses** recalculated aberrations
r.m.s. Tilt	transversal rms of the given aberration (in arcsec)
d80	diameter containing 80% of energy for a given aberration (in arcsec)
r.m.s. wave	r.m.s. of the wavefront surface for a given aberration (in nm)
r.m.s. variation	r.m.s. of the set **# of IA analyses** for a given aberration (in nm)
M2 absolute positions	last computed M2 position for absolute correction (in mm)
M2 differential positions	last computed M2 position variation for differential correction (in mm)

4.2 System initialization

The system initialization is performed as part of the startup of the telescope in the afternoon. The purpose is to start everyday with the telescope in the same configuration and make sure that the system behaves properly. One should be aware of the fact that the startup is done for the Nasmyth side that will be used at the beginning of the night and that it is not possible to start the system for both Nasmyth focii at the same time. This means that when one changes from Nasmyth focus for observation during the night, one has to initialize the system at that moment for the other side (See section 4.4). The following sequence of actions has to be carefully executed:

1. The AO user panel should be started from **tcs** account on **xt5tcs** terminal. This is conveniently done by using the predefined key in the mouse menu.
2. When this first panel is up, press button "**engineering interface**" to get the AO engineering panel. At that point, you can iconify the AO user panel.
3. Open the AO CCD panel corresponding to the Nasmyth side that will be used.
4. Open via mouse key the RTD of the wavefront sensor camera that will be used (either A or B) and attach it.
5. The CCD control SW is successively stopped and started using the buttons *shutdown* and *startup* on the previous panel
6. An exposure is manually performed via the interface previously opened to check that the CCD works properly. You might get at that moment a saturated image. This is normal as the CCD does not have any shutter. But this should not be the case if subsequent images are taken.
7. Back on the Engineering panel, the **INITAO** button initialize the AO system. The substate of the AO control process (indicated in the upper left corner of the panel) should change to **BOTH_READY**
8. On the Engineering panel, the '**REFIA**' command performs a reference image analysis. The number of detected reference spots (displayed in the lower left) should be close to 800 spots. If not, check the SH image on the RTD.
9. Check that the focus offset for both sides are set to 0. If not, press button '**Reset offset to 0**'
10. Perform a cross reference by pressing button '**CROSS REFERENCE**'. Physically another reference image is taken and compared with the reference. Obviously, the measured aberrations should be very close to 0 (typically between 0 and 0.02 in d80).
11. Finally, after selecting '**M1 & M2**' option for Targets, press '**INIT M1 & M2**'. The accuracy of correction on the M1 should be below 1.5 Newton. If it is not the case, press again '**INIT M1 & M2**'. If the second attempt does not permit to reach the specification, contact the NTT support engineer.

4.3 Scheme for night-time use

The default operation mode during night time at the NTT is as follow:

- at each preset to a new field, the AO should be used to optimize the telescope optics **before** starting observing (if not possible in differential mode, this should be done in absolute mode)
- then the AO should be run **during** observation. The system is foreseen so that this is transparent for the observer, this is the so-called parallel mode. This operation is only performed in differential mode. If this is not possible (bad weather conditions, no suitable guide star), the AO activities are suspended. In such a case, it is imperative to optimize again

the telescope optics when the telescope has moved by more than 15 deg in altitude either with a nearby star in differential mode or in absolute mode.

4.3.1 Differential mode

At each preset, the TCS searches automatically for a guide star and positions accordingly the guide probes so that the guide star image falls on the reference light image on the AG screen.
If the guide star is too bright, the wavefront sensor detector will saturate and *SEQAO* command will fail. In this case, apply workaround given in 3.2.3. If the guide star is too faint, check if there is no brighter guide star available on the AG control panel. If not, differential mode cannot be performed in this position. Either move telescope to a nearby field to find an adequate sensing star (and then go back to the astronomer field) or just perform an absolute force setting.
Because of pointing and guide probe positioning inaccuracy, the operator might have to adjust manually the guide probe position so that the guide star is exactly at the position of the reference light (**Important**: this is done by moving the guide probe and not the telescope as the telescope position is **fixed** by the astronomer).Then the AO system can be used. The whole procedure is summarized below:

1. adjust guide probe position in order to have guide star on reference light position on AG screen. This operation should be done within 5 pixels on the AG screen. If it is too large (typically 20 pixel), the AO SW will fail complaining for 'tilt too large'.
2. set # *of measurements* to **1**
3. set # *of IA analyses to be av.* to **3**
4. set *Targets* to **none**
5. press *STORE* button
6. press *SEQAO* button and wait until *command state* goes back to **IDLE**
7. If fitting rms is lower than 0.18, then do the following
   a. set *Targets* to **M1 and M2**
   b. set *Type* to **Differential** and press *STORE* button
   c. press *ONECOR* button and wait until *command state* goes back to **IDLE**

   else

   d. Stop here the differential mode: the aberrations computed are not reliable, no correction can be applied using the differential mode
8. set *Targets* to none
9. press *SEQAO* button and wait until *command state* goes back to **IDLE**
10. check that d80 of aberrations are all below 0.10 arcsec. If it is not the case, go to step 7. If you have not converged after 2 iterations, report it to the support engineer.
11. Start the scientific exposure (no through focus exposure is needed any more)

IMPORTANT: As explained in section 2.1.4.1, the aberrations computed by the wavefront sensor cannot be trusted if the fitting rms is larger than 0.18. Currently the SW does not offer to prohibit correction when fitting rms is larger than a given threshold (this has been requested to the SW group). This complicates a bit the procedure as this check has to be done manually as detailed in the procedure. Once the new SW version will be installed, it will be possible to set directly the Target to 'M1 and M2' instead of 'none' (step 4) and drop step 7.

4.3.2 Absolute mode

The absolute mode of active optics does not require any sensing object. The ideal M1 support forces and M2 position are computed using a model of the telescope using as parameters the Serrurier temperature and the telescope altitude. This operation can be performed whatever the telescope altitude is, the only restriction is that the telescope should not be presetting at that moment (there is a SW interlock implemented in the msw module preventing it). Symmetrically the telescope cannot be presetted while M1 force or M2 position are adjusted. To use the absolute mode, do the following:

1. set Targets to *M1 and M2*
2. press *STORE* button
3. press *ONECAL* button and wait until *command state* goes back to IDLE

As can be seen in the sequence, the parameter Targets can be set to different values. Setting it to *None* would not be very useful. Indeed in this case, the M1 forces and M2 positions are computed but not applied.

IMPORTANT: The law defining the M2 position along Z axis is a function of the Nasmyth focus currently in use (there is an offset of -0.431 mm when passing form side B to side A).

4.3.3 Parallel mode

The parallel mode is very similar to the differential mode except that the wavefront sensing is running cyclically (command CYCLAO instead of SEQAO) and the corrections are applied when necessary and under strict conditions.
The philosophy behind the parallel mode is to optimize the telescope optical quality not only at each field change but also during scientific exposure. The first step is to monitor the optical quality of the telescope. As the guide star light is shared between the autoguider and the wavefront sensor, there is no problem to use the wavefront sensor while observing as long as the guide star is of sufficient magnitude. As we want to correct slow varying aberrations, the idea is to average a large number of individual aberrations measurements (typically 5 or more). The application of the correction computed is then only done if the aberrations measured are off specification (at least one of the aberrations larger than 0.15 arcsec). This specification is not absolute and as explain in section 3.1.2, if the outside seeing is excellent, this specification should be made more stringent while if outside seeing is lousy, one can tolerate higher aberrations.
The typical sequence of action is as follow:

1. We start from the situation where a suitable guide star is available and has been centred on the position of the reference light to perform the initial AO optimization (See 4.3.1)
2. Check that the beamsplitter is in position (adapter panel) and start autoguiding with option **BOX2STAR**.
3. If necessary, adjust the AG integration time to optimize S/N staying in the following range:
   $0.5\ s < T < 5.0\ s$
4. Select *Targets* '**None**' and set *# of IA analyses to be av.* to **5**
5. Press **STORE** button
6. Press **CYCLAO**

7. If necessary, adjust the IA integration time to optimize S/N. The maximum count on the SH should be ideally around 2500 to 3000 ADU. The integration time should be kept in the following range:

   10 s < T < 60 s
8. Monitor the d80 of aberrations

   If the d80 of one of the aberrations gets higher than 0.15 arcsec typically, you should perform a correction -> see specific instructions.
9. When one wants to change of field, press button **STOP** on AO panel.

Directions to perform a correction in parallel mode:

a. Pause the exposure on the instrument
b. Press **STOP** button on AO panel and wait for the command state to switch to **IDLE**
c. Select Targets '**M1 and M2**' correction and press **STORE**.
d. Select Type '**Differential**' correction and press **STORE**.
e. Press **ONECOR** button
f. Once correction finished, select '**Non**e' correction and validate pressing **STORE** button.
g. Continue the exposure on the instrument
h. Press **CYCLAO**

4.4 Change of instrument

As explained previously, there is one wavefront sensor for each Nasmyth focus. This means that when one switches from one focus to the other, another wavefront sensor will be used. Also some parameters like the trombone defocus offset should be set differently according to the instrument used. Therefore part of the initialization process has to be repeated. The following list of actions have to be executed:

1. Do a STOP TCS on the TCS main panel (Telescope state goes to STANDBY).
2. Select the new instrument by pressing the corresponding button on TCS main panel.
3. Restart TCS on the TCS main panel.
4. Close the AO engineering panel.
5. Deiconify the AO user panel.
6. When this first panel is up, press button "**engineering interface**" to get the new AO engineering panel. Check that the Nasmyth focus name displayed on this panel is correct. At that point, you can iconify the AO user panel.
7. Open the AO CCD panel corresponding to the Nasmyth side that will be used. The one corresponding to the other Nasmyth side is either closed or iconified.
8. Open the RTD of the wavefront sensor camera that will be used (either A or B) and attached.
9. Stop and restart the CCD control SW using the buttons *shutdown* and *startup* on the previous panel
10. Perform a manual exposure via the interface previously opened to check that the CCD works properly. You might get at that moment a saturated image. This is normal as the CCD does not have any shutter. But this should not be the case for subsequent images.

11. Back on the Engineering panel, initialize the AO system with the **INITAO** button. The substate of the AO control process (indicated in the upper left corner of the panel) should change to **BOTH_READY**
12. On the Engineering panel, the '**REFIA'** command performs a reference image analysis. The number of detected reference spots (displayed in the lower left) should be close to 800 spots. If not, check the SH image on the RTD.
13. Check that the focus offset for both sides are set to 0. If not, press button '**Reset offset to 0**'
14. Perform a cross reference by pressing button '**CROSS REFERENCE**'. The measured aberrations should be very close to 0 (typically between 0 and 0.02 in d80).

5 DATA LOGGING

5.1 A non standard logging system

At the time of SW writing, the standard VLT logging was not yet available. Therefore the version currently used at the NTT (actcal version 1.50.1.1) uses a basic data logging system which will be replaced by the standard one's as soon as the most recent version of **actcal** SW module will be implemented. As for the logging done at the level of the primary mirror control SW (module specific to the NTT: nttm1), the logging will stay as it is as no new version has been released that would use the VLT standard logging.

5.2 Which data are logged ?

There are currently three log files updated when the AO system is used:

- logging of primary mirror setting activities (done on the *lt5m1* LCU, **nttm1** SW module)

  file location: **$VLTDATA/ENVIRONMENTS/lt5m1/output/m1Setting.log** (on *wt5tcs*)

  Every force setting performed on the primary mirror is registered together with the exact time, the type of correction (differential or absolute), the state of the telescope at that moment (altitude and altitude velocity), the amplitude of the correction and then all the parameters specifying the final setting accuracy obtained.
- logging of the averaged efficiency of the primary mirror setting system (done on the lt5m1 LCU, **nttm1** SW module)

  file location: **$VLTDATA/ENVIRONMENTS/lt5m1/output/actPerformance.log** (on *wt5tcs*)

  For each actuator, the cumulated force change and moving time are computed as well as the effective temporal gain (cumulated force change divided by moving time). This file is usually resetted every month, therefore it is possible to monitor the efficiency of each actuator over time.
- logging of general AO activities (done at WS level, **actcal** SW module)

  file location: **$VLTDATA/tmp/aoActivities.log** (on *wt5tcs*)

  This file includes the wavefront sensor measurements together with important parameters as well as the corrections sent to the M1 and the M2.

The log files are plain ASCII files and the logging format is detailed in the files with extension **.doc** instead of **.log** (same directory, same name).

Example:
file describing the content of m1Setting.log file:
$VLTDATA/ENVIRONMENTS/lt5m1/output/m1Setting.doc (on *wt5tcs*)

Extract of each log file as well as the description of the content is also given in Appendix A.

5.3 Use of the logged data

The log data can be used for many different purposes

- understand a problem that occurred at a given moment
- monitoring of the system (variation of M2 setting efficiency with time, frequency of correction, ...)

- database for statistical analysis (aberration vs zenith distance, M2 position vs Serrurier temperature, ..)
- automatic creation of input file for measurement of field astigmatism centre

IMPORTANT: The log files can be used freely but the original files cannot be modified. Therefore, if you want/need to work on these files, please make your own copy and leave the original untouched.

6 BASIC SYSTEM MONITORING/MAINTENANCE

6.1 Cleaning of AO log files

This operation is now fully automatic. On any **wt5tcs** terminal (under **tcs** login), type command:

nttSaveAndCleanAoLogs

The AO log files (aoActivities.log, m1Setting.log and actPerformance.log) are copied to a specific directory on kila (**~nttdoc/maintenance/actOpt/aoLog**) with a name including a timestamp.

Example:
files copied to ~nttdoc/maintenance/actOpt/aoLog after running nttSaveAndCleanAoLogs:
aoActivities.29Nov98 m1Setting.29Nov98 actPerformance.29Nov98

Meanwhile they are replaced by clean files on wt5tcs ("clean" means either empty files (aoActivities.log, m1Setting.log) or file with parameters initialized (actPerformance.log)).

Periodicity: every month

6.2 Measurement of field astigmatism centre

The center of field astigmatism is a very important parameter of the AO software. Indeed the AO system measures the astigmatism at a given point in the field and this is usually not the center of the field whereas we are interested in correcting the aberrations affecting the **center of the field**. For all the aberrations except astigmatism, the aberrations can be considered as constants over the whole telescope field. For the specific case of astigmatism, the measured value is the sum of the astigmatism affecting the telescope plus the so called field astigmatism. The shape of the field astigmatism is defined by the optics of the telescope but the exact position of this field astigmatism with respect to the guide probes (axes orientation and center position) can be defined by **three parameters** (2 position offsets and one angle). The value of these 3 parameters depends on the alignment of the telescope optics. Actually the determination of these parameters is also an indirect mean to assess the state of alignment of the telescope.

Periodicity: every 6 months

6.2.1 Measurement procedure

The measurements should be collected during a period with good seeing (less than 1 arcsec) and stable local conditions (especially thermally). The measurement should be done rapidly (typically 30 to 40 minutes) to avoid variations in the aberrations affecting the telescope.

1. Initialize telescope optics at zenith (button '**INIT M1 & M2**')
2. Choose a field at -70 deg in declination and 2 hours after meridian where there is a suitable star for the wavefront sensor (magnitude between 11 and 12 to have a good S/N ratio with a 30 sec integration time)
3. Move guide probe to centre field.
4. Use AO system in differential mode (SEQAO averaging 3 measurements) with full correction (M1 & M2) to reduce the aberrations to a minimum.
5. Check that the fitting rms is not too high and that the maximum counts on the wavefront sensor is between 1500 and 3000 ADU (too low would mean a degraded S/N ratio while if it

is too close to the saturation limit, there is a risk to reach this limit at some point during the sequence). If necessary, choose another star with a different magnitude so that the maximum counts falls in this range.

6. Put the M2 in its default position along X and Y axis (currently 0.59, 0.49)
7. Use AO system in differential mode (SEQAO averaging of 3 measurements) **without** correction to check that the residual aberrations are low.
8. Then move the star around by offsetting the telescope and the guide probe at the same time. Specific sheets for each Nasmyth focus have been designed that include telescopes offsets as well as the corresponding guide probe positions (given in Appendix B).
   a. For each field position, centre the star on the reference light position by **offsetting the telescope** (and not the guide probe).
   b. Use AO differential mode (SEQAO averaging 3 measurements) **without** corrections.
   c. Once finished, move to the next position

When this procedure is finished, you can start reducing the data as specified in the next section.

6.2.2 Data reduction

The data reduction is performed using directly the AO log data. These data are stored on wt5tcs workstation in file **/vlt/tmp/aoActivities.log**

1. Extract the log data relative to the test you just have done from the AO log file. The data extracted should be from the first set aberrations measured at centre field without correction until the last aberrations measured at the centre.
2. Name this file **astMap_A.DDMMYY** or **astMap_B.DDMMYY** according to the Nasmyth side used (where DDMMYY is the time stamp).
3. Ftp this file to **nttt** account, directory **maint_ia/field_astig/data_taking**
4. Copy this file to **~nttt/maint_ia/field_astig/reduction/astMap.in**
5. Go to directory **~nttt/maint_ia/field_astig/reduction**
6. Run script **reduce** with a parameter specifying how many measurements have been averaged at each field position (usually 3)
7. The results are displayed on the screen. Copy them to file **results_A.DDMMYY** or **results_B.DDMMYY** and move this file to directory **~nttt/maint_ia/field_astig/results**

The results displayed contains actually 5 parameters: alpha_x, alpha_y, offsetAngle_x, offsetAngle_y and angleGp. Actually offsetAngle_x and offsetAngle_y can be deduced from alpha_x and alpha_y via a simple multiplication by a constant. They are displayed as the current AO SW contains those 4 parameters even if there are linked and can be reduced to 2 independent parameters. The offsetAngle corresponds to an offset in the adapter plane in arcsec equivalent on the sky while the alpha corresponds to an offset of the secondary mirror around the neutral point with respect to its theoretical position.
It is **important** to verify the correctness of the fitting (done by the **reduce** script). This can be assessed by checking the residual rms of the fitting. This value is bad if higher than 250 nm, and excellent if lower than 100 nm.

A good tool to check the correctness of the current field astigmatism parameters in the SW in to run **astMapData** program with the following parameters:

- number of measurement averaged at each position (usually 3): parameter #1 = 3

- display of d80 of astigmatism: parameter #2 = 5

Therefore type command **astMapData 3 5** and a display will pop up showing you the equivalent center astigmatism computed for each field position (given in unity of d80). As we can consider that the astigmatism at the center is constant during the test, we should get a somehow flat curve and close to 0 as astigmatism has been reduced to a minimum at the beginning. If this is the case, it means that the SW works properly with the current values of the 3 field astigmatism parameters (very likely the current values are close the new values computed). On the other hand, if there are large variations, it means that the current field astigmatism parameters are imprecise. In any case, any change of the field astigmatism parameters used in the SW cannot be made lightly and more tests should be performed to double check the results and understand the reasons of the sudden changes.

6.2.3 Implementation in the SW

As said in the previous section, the implementation is only allowed if a large change in the field astigmatism parameters has been measured and confirmed. Indeed this change is a major one and takes typically 5 hours during day time plus 2 hours at night time for checking. **This change can only be done by the SW group.**
In the SW, these parameters are defined in the overloading file of the wt5tcs WS database. This is done on wt5tcs WS in file **~nttmgr/NTTSourceJAN98/ntt/ENVIRONMENTS/wt5tcs/dbl/TCS.db**

```
ATTRIBUTE  Table  control:calcParams:fieldAstigParams.param (actcalNO_OF_FOCI,
   rtBYTES32     focus,
                 double      constB0,
                 double      constB1,
                 double      constB2,
                 double      offsetAngleX,
                 double      offsetAngleY,
                 double      alphaX,
                 double      alphaY,
                 double      centerGpX,
                 double      centerGpY,
                 double      angleGp,
                 double      plateScale,
                 double      factorAltitudeAngle,
                 double      factorRotatorAngle
   )

BEGIN
      Value ( (mswNASMITH_A_STR_FOCUS, -24367.90, 30071.91, 176.77, 0.0036, 0.0095, 0.0052,
0.0146, 167.3, 166.9, -87.5, 0.1862, -1.0, 1.0),
         (mswNASMITH_B_STR_FOCUS, -24367.90, 30071.91, 176.77, 0.0038, 0.0098, 0.0057, 0.0151,
167.7, 161.7, -87.1, 0.1862, 1.0, 1.0) )
    END
```

This file is part of ntt module which means that if one wants to change the value of the previous parameters, one should do the following:

1. check out ntt from archive
2. Modify the file ~nttmgr/NTTSourceJAN98/ntt/ENVIRONMENTS/wt5tcs/dbl/TCS.db

3. Rebuilt wt5tcs DB
4. restart AO SW

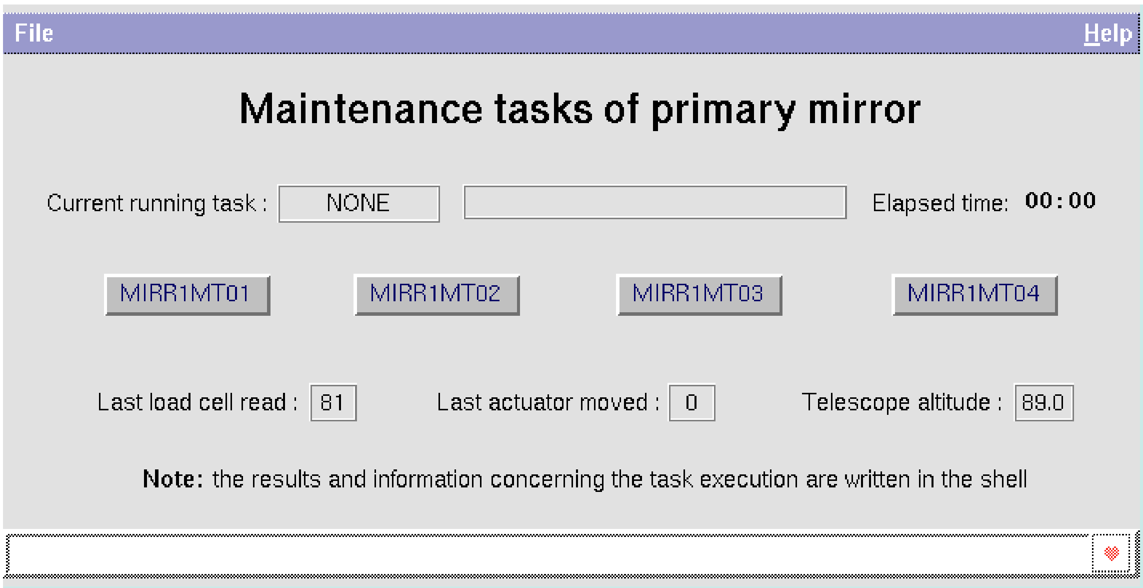
WARNING: As any SW change, this change cannot be done out of test period. Moreover, the same test should be repeated once the new parameters are active to make sure that the new field astigmatism parameters are correct. If this is not the case, contact Lothar NOETHE.

6.3 Primary mirror maintenance

Different parameters characterizing the mechanical and electronic health of the primary mirror should be regularly monitored. To this end, a specific user interface has been designed that can be called from any **wt5tcs** window (under login **tcs**) with the command:

nttadmMirr1

The following panel will pop up on the terminal:



4 basic maintenance tasks have been defined:

- Measurement of the reading noise of each load cell (MIRR1MT01)
- Measurement of the current consumption of each actuator motor (MIRR1MT02)
- Measurement of the temporal gains of each actuator (MIRR1MT03)
- Measure the astaticity of all actuators (MIRR1MT04)

These tasks should be executed on a regular basis. The following table gives important indication for the execution of these tasks (frequency, duration, required state of the telescope/system at the moment of execution, necessity of manual intervention during execution).

task	execution frequency	duration	requirements	fully automatic ?
MIRR1MT01	every month	3.5 min	nttm1 online telescope at zenith	Yes
MIRR1MT02	every month	20 min	nttm1 online telescope at zenith	Yes
MIRR1MT03	every month	45 min	nttm1 online telescope at zenith	Yes
MIRR1MT04	every month	15 min	nttm1 online nttalt online telescope at zenith	confirmation needed when moving alt axis

REMARK: The MIRR1MT04 task is not fully automatic just **for safety reason**. Indeed, unlike the other tasks, this one moves the telescope in altitude and therefore it has been decided to add a confirmation pop up menu before each motion of the altitude axis.

The execution of each task can be monitored directly on the interface (display of last read channel, last moved actuator, altitude of the telescope) but also on the shell where the interface has been started from. On the shell will appear information explaining failure if any or if successful, a first analysis of the data acquired. In addition to the display of the results on the shell, some log files are updated or created on **wt5tcs** machine:

1. An *history file* (for each task) which is updated with a new line indicating the date and the results of the data analysis.
2. Also the *complete results* are saved in a specific sub-directory with file names containing a time stamp for easy identification.

The location and syntax of these log files are given for each task in the next sections.

IMPORTANT: If some actions has to be executed on **any** element of the M1 actuators (load cell, motor, counterweight, ...), this has to be reported in the following file:

/vltdata/SPC/mirror1/Actions

The current content of this file is given in Appendix C.

VERY IMPORTANT: **ALL** actuators should be in position and connected in order to have the AO system working. This means that for any repairing action, the actuator should be remounted back and reconnected at telescope startup time. If more time is needed, a spare actuator has to be used. We currently have two spare actuators, one for each actuator type we use on the NTT (high head for the outside ring and low head for the 3 internal rings).

6.3.1 Measurement of the reading noise

The principle of measurement is the following:

- each load cell is read 25 times in a row
- the standard deviation of this time series is computed for each actuator

The specification for the standard deviation is set to 1.0 N. The command MIRR1MT01 executes automatically these actions and the results are logged in the following files on **wt5tcs** machine:

history file:	**/vltdata/SPC/mirror1/MIRR1MT01.SPC** contains the date and number of load cells out of specifications
complete results:	**/vltdata/SPC/mirror1/cellNoise/loadStat.DDMMYY** contains the reading noise (stdDev) of each load cell and the full analysis

REMARK: the test is done for channels 1 to 82. As explained in [6], channels 1 to 78 corresponds to the load cell bearing the same number while 79 to 82 are special channels and they are not considered for the noise measurement analysis.

If the reading noise of a given load cell is consistently largely over the specification (1.0 N), it is recommended to change the load cell (this has never happened so far since 1989 !!!)

6.3.2 Measurement of the current consumption

The principle of measurement is the following:

- a motor is pulsed during 5 seconds in one direction
- the current consumption is measured approximately 30 times during the motion and averaged
- the motor is pulsed during 5 seconds in the opposite direction
- the current consumption is measured approximately 30 times during the motion and averaged

The motors having one of their current consumptions higher than 25 mA are considered as 'to be monitored'. The normal current consumption is around 8 to 10 mA and the fuse will blow up when the current consumption reaches a value of 120 mA typically. This means that the limit of 25 mA is quite conservative. Nevertheless it has been noticed that once the current consumption stars to increase, the degradation gets faster and faster.
These actions are performed in sequential mode, this explains why this task lasts about 20 minutes. The results are logged in the following files on **wt5tcs** machine:

history file:	**/vltdata/SPC/mirror1/MIRR1MT02.SPC** contains the date and number of motors '*to be monitored*'
complete results:	**/vltdata/SPC/mirror1/motCurrent/motCurrent.DDMMYY** contains the current consumption (inc. and dec.) of each motors and the full analysis

If the current consumption of a given motor reached the level of 100 mA, the actuator has to be brought to the mechanical workshop during daytime (the AO system cannot work with a missing actuator). The actions to be done are to measure the consumption of the motor once dismounted to identify if the motor + gear box itself (the motor and gear box form a subsystem that cannot be dismounted) has a high current consumption or if it is due to the mechanical system of the actuator. If the motor + gear box have already a high current consumption without mechanical load, it should be replaced by a new unit (around 30 motor + gear box units have been replaced on the NTT since 1989). In addition the mechanical part of the actuator should always undergo a complete adjustment/cleaning by the mechanics.

6.3.3 Measurement of the temporal gains

The principle of measurement is the following:

- a given load cell is read 10 times and averaged
- the motor on the same actuator is pulsed during 15 seconds in one direction
- the load cell is read 10 times and averaged
- the motor is pulsed during 15 seconds in the opposite direction
- the load cell is read 10 times and averaged

The temporal gains are computed for each direction of motion by dividing the force variation (in N) by the duration of motion (in sec.). The normal value is around 2.8 N/sec and therefore the normal range has been set to 2.4 N/s to 3.0 N/s.
The results are logged in the following files on **wt5tcs** machine:

history file:	**/vltdata/SPC/mirror1/MIRR1MT03.SPC** contains the date and number of actuators having a temporal gain higher and lower than normal
complete results:	**/vltdata/SPC/mirror1/tempGain/tempGain.DDMMYY** contains the temporal gains (inc. and dec.) of each motors and the full analysis

If the temporal gains are consistently off specification, the actuator should be dismounted to undergo a thorough mechanical check. This is actually the case of actuator #63 but nothing faulty has never been found so far.

6.3.4 Measurement of the astaticity

The measurement principle requires to move the telescope in altitude. Indeed the telescope is moved from zenith to horizon (15 deg altitude) and back to zenith by steps of 15 deg. At each position, the force exerted by each actuator is measured and recorded. At the end, a least square fit is performed for each actuator (actuator force as a function of zenith distance) using the following function:

$$F = a + b \times \cos(ZD)$$

where **a** can be interpreted as the spring force and **b** as the weight component. The least square fit yield a fitting rms for each actuator. The specification in terms of fitting rms has been set to 3.0 N. Also the maximum deviation from the fit is monitored with a maximum acceptable value set to 10 N. Finally the estimated weight of the mirror is computed adding all the **b** terms for each actuators (should be close to 6060 kg) while the sum of the **a** terms should be close to 0 as this is the aberration force.

history file:	**/vltdata/SPC/mirror1/MIRR1MT04.SPC** contains the date and number of actuators having a fitting rms higher than normal and the maximum deviation higher than normal
complete results:	**/vltdata/SPC/mirror1/astaticity/astatic.DDMMYY** contains the fitted coeff. a and b, the fitting rms and theoretical spring and counterweight forces and full analysis **/vltdata/SPC/mirror1/astaticity/maxDev.DDMMYY**

contains the maximum deviation (positive and negative) from the fitting and the complete analysis

For the actuators that failed the astaticity test, a thorough mechanical test should be performed at the workshop.

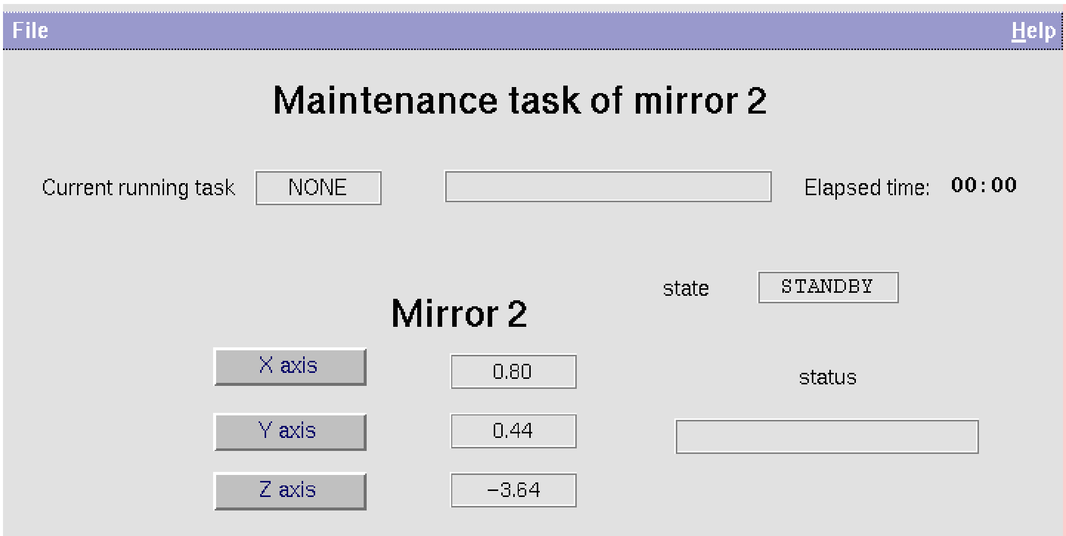
6.4 Secondary mirror monitoring

Periodicity: every 6 months

Different parameters characterizing the mechanical and electronical health of the primary mirror should be regularly monitored. To this end, a specific user interface has been designed that can be called from any **wt5tcs** window (under login **tcs**) with the command:

nttadmMirr2

The following panel will pop up on the terminal:



There is one button for each axis and each of them has to be pressed sequentially to have the parameters measured for each axis. The execution of these tasks is fully automatic but cannot be done in parallel, wait until the previous task is finished before checking the next axe.

The execution of each task can be monitored directly on the interface but also on the shell where the interface has been started from. On the shell will appear information explaining failure if any or if successful. In addition to the display of the results on the shell, some log files are updated or created on **wt5tcs** machine:

1. An *history file* (for each task) which is updated with a new line indicating the date and the results of the data analysis:

   /vltdata/SPC/mirror2/MIRR2MT01.SPC

2. Also the *complete results* are saved in a specific sub-directory with file names containing a time stamp for easy identification:

   /vltdata/SPC/mirror2/motCurr/*.dat

IMPORTANT: If some actions have to be executed on **any** element of the M2 axes (lubrification, dismounting, change of spindle, ...), this has to be reported in the following file:

/vltdata/SPC/mirror2/Actions

6.5 Wavefront sensor monitoring

6.5.1 Cross reference

The wavefront sensor is usually used to compare a Shak-Hartmann pattern obtained with a reference light with a Shak-Hartmann pattern obtained with the guide star light going through whole telescope optics (M1/M2/M3). In order to assess the noise of the system, it is possible to use the wavefront sensor so that it compares two wavefronts obtained with the reference light. We should theoretically get zero aberrations. Therefore what we get is directly the noise affecting the wavefront sensor.
This test is performed daily as part of the telescope startup. At that time, it is asked to the operator to make sure that none of the 7 aberrations measured is larger than 0.03 arcsec in d80.
When large aberrations have been detected when doing cross reference, the problem has been usually been tracked down to some condensation problem on the detector window.

REMARK: cross reference can also be advantageously used to measure the flexure inside the adapter (trombone + collimator). One simply has to make a reference wavefront sensing with the rotator in a reference position (let's say 0 deg). Then cross references can be perform at different rotator angle (from -180 deg to +180 deg with steps of 15 deg for example). Then the variations of focus and tilt aberrations measured yield directly the result.

6.5.2 Wavefront sensor background monitoring

Each time the wavefront sensor is used, the value of background is recorded in the automatic log file on **wt5tcs** machine (*/vltdata/tmp/aoActivities.log*). A tool has been developed that allows to display automatically the variations of this specific item. To this end, each time the AO log files are cleaned and saved on kila under the **nttdoc** account (See section 6.1), the aoActivities.DDMMYY file can be ftp'ed manually to **nttt** account under directory *~nttt/maint_ia/logAnalysis*
Then do the following:

- **cp aoActivities.DDMMYY aoActivities.log**
- **setenv DISPLAY 134.171.xx.yy:0.0**
- **aoLogAnalysis 3**
- a window will pop up displaying the background measurements for side A
- press enter in the shell to exit (a postscript file is automatically created: *backgrd_A.ps*)
- **aoLogAnalysis 4**
- a window will pop up displaying the background measurements for side B
- press enter in the shell to exit (a postscript file is automatically created: *backgrd_B.ps*)

In addition to the display, you should check the range of variations of the background that is displayed on the shell. Indeed, as the range displayed in ADU is fixed (0 to 500), large values would not appear. The curves should be examined to detect a possible increasing trend in the level of the background, this would clearly mean than the detector is degrading.

6.6 Aberrations lookup table determination

periodicity: every 6 months

6.6.1 Use of the lookup table

The absolute mode of the AO system computes the ideal M1 support forces (besides the ideal M2 position) considering the following contributions:

- fraction of M1 weight supported by each actuator (varies with the cosines of zenith distance)
- spring force to compensate for M1 spherical aberration (constant with zenith distance)
- additional force to compensate the aberrations appearing with zenith distance.

This last contribution is computed using the aberrations lookup table. This table gives the aberrations affecting the telescope for discrete zenith distances ranging from 2 deg to 75 deg. The AO SW calculates the exact aberrations affecting the telescope for a given zenith distance by interpolation. The interpolated aberrations are stored in the wt5tcs database:

@wt5tcs:Appl_data:TCS:act:control:coeffs:interpol.param(0:17,0:2)

Similarly the M2 ideal position is computed using the interpolated aberrations of defocus, coma and spherical aberrations.

IMPORTANT: Only the aberrations having an **active** flag set to 1 will be taken into account in the calculation of the additional force. These flags (one for each aberrations) are initialized in the overloading file of the wt5tcs WS database. This is done on wt5tcs WS in file **~nttmgr/NTTSourceJAN98/ntt/ENVIRONMENTS/wt5tcs/dbl/TCS.db**

```
ATTRIBUTE  Vector control:calcParams:calibCoeffs.active (actcalMAX_NUM_MODES, rtINT32)
    BEGIN
     Value (0, 1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0)
    END
```

6.6.2 Filling of the table

The table has been filled with numbers computed after processing the data contained in file **aoActivities.log**. This file has to be filtered to **only** keep the image analysis data that have been performed after the telescope had been initialized at zenith. This means typically the data corresponding to one zenith distance position for each night can be used (the first image analysis) as the optical configuration is usually modified afterwards to reduce aberrations. The steps to be followed can be summarized as follow:

- copy the last **aoActivities.log** file from nttdoc account (directory *~nttdoc/maintenance/actOpt/aoLog*) to nttt account directory *~nttt/maint_ia/lookup_tab* and rename it **aberration.dat**
- filter aberration.dat file in order to keep only image analysis data (only RECALC section) that have been obtained just after a absolute initialisation of the telescope at zenith (should corresponds to the first sequence of the night, usually 3 image analysis)
- process the data: **aoAnalysis C 0 0.16**

The program computes the linear fit for each of the aberration and also a direct table of aberrations for values of zenith distances ranging from 5 to 75 deg. This table has exactly the format that has to be input in the AO but first of all the data should be analyzed to define which aberrations have been precisely fitted. This can be assessed by checking the rms of the fit compared to the amplitude of the variation modeled. Also this operation should be repeated on several files aoActivities.log to check consistency.
The case of the focus is a bit different as the M2 position along Z axis is computed as a function of zenith distance **and** Serrurier temperature. Also the telescope operators moves usually manually the M2 before an image analysis to have a proper focus (the absolute force setting is done as part of the startup and therefore with a quite different Serrurier temperature). Therefore the law of variation of defocus with zenith distance has been obtained using directly the focus wedge data or through focus data.

Once the aberrations having a repeatable behavior are identified, the corresponding columns can be filled in the lookup table. This table is initialized in the overloading file of the wt5tcs WS database. This is done on wt5tcs WS in file **~nttmgr/NTTSourceJAN98/ntt/ENVIRONMENTS/wt5tcs/dbl/TCS.db**

```
ATTRIBUTE  Table  control:calcParams:calibCoeffs.param (actcalMAX_NUM_ZD_ENTRIES,
                  double zd,
                  double mod1,  double angle1,
                  double mod2,  double angle2,
                  double mod3,  double angle3,
                  double mod4,  double angle4,
                  double mod5,  double angle5,
                  double mod6,  double angle6,
                  double mod7,  double angle7,
                  double mod8,  double angle8,
                  double mod9,  double angle9,
                  double mod10, double angle10,
                  double mod11, double angle11,
                  double mod12, double angle12,
                  double mod13, double angle13,
                  double mod14, double angle14,
                  double mod15, double angle15,
                  double mod16, double angle16,
                  double mod17, double angle17,
                  double mod18, double angle18
                 )
   BEGIN
    Value ( (2,    0,0, 0,0, 0,0,     0,0,    0,0,    0,0,     0,0,    0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          ( 5,   0,0,  712,0, 0,0, 0,0, 248,-81,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (15,   0,0,  366,0, 0,0, 0,0, 140,-60,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (25,   0,0,   20,0, 0,0, 0,0, 102,  1,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (35,   0,0, -326,0, 0,0, 0,0, 183, 43,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (45,   0,0, -672,0, 0,0, 0,0, 298, 56,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (55,   0,0, -1018,0, 0,0, 0,0, 420,62,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (65,   0,0, -1364,0, 0,0, 0,0, 545,65,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0),
          (75,   0,0, -1710,0, 0,0, 0,0, 670,67,  0,0,  0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0)
          (0,   0,0, 0,0,   0,0,   0,0,   0,0,   0,0,    0,0,   0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0)
          (0,   0,0, 0,0,   0,0,   0,0,   0,0,   0,0,    0,0,   0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0, 0,0)
          )
   END
```

This table is made of up to 20 ligns (up to 20 zenith distances) by 18 aberrations (1 coefficients + 1 angle for each) plus the zenith distance. The detail is given below for the case of the NTT:

column 0:	value of zenith distance
column 1:	modulus of tilt = 0
column 2:	angle of tilt = 0
column 3:	modulus of defocus
column 4:	angle of defocus = 0
column 5:	modulus of coma
column 6:	angle of coma
column 7:	modulus of spherical aberration
column 8:	angle of spherical aberration = 0
column 9:	modulus of astigmatism
column 10:	angle of astigmatism
column 11:	modulus of triangular coma
column 12:	angle of triangular coma
column 13:	modulus of quadratic astigmatism
column 14:	angle of quadratic astigmatism

6.7 Determination of the temperature dependent law of defocus

In the wt5tcs, there are two attributes that defines the variation law of M2 position versus Serrurier temperature. These attributes are initialized in the overloading file of the wt5tcs WS database:

ATTRIBUTE double control:calcParams:m2TempCorrPar.constantTerm -4.092
ATTRIBUTE double control:calcParams:m2TempCorrPar.linearTerm 0.0711

The dependence law is modeled by a linear function of Serrurier temperature (exactly the temperature of the tube 1 of the Serrurier). This law has been determined fitting the through focus data that have been obtained with EMMI (around 200 measurements). A specific program has been written that processes directly the log data RILDCT04.SPC . This program is installed on kila machine under directory *~nttt/maintenance/telescope/focusTel* To run it and get a graphical display, type:

telFocusFit 1

The current law of variation currently used in the SW is: -4.092 + 0.0711 * T
As there is an offset between M2 position along Z axis depending on the Nasmyth used, an offset depending on the Nasmyth side used is added. These offsets are initialized in the overloading file of the wt5tcs WS database as he last column of the following table:

```
ATTRIBUTE  Table  control:calcParams:m2ZenithPos.param (actcalNO_OF_FOCI,
   rtBYTES32    focus,
                rtDOUBLE    posX,
                rtDOUBLE    posY,
                rtDOUBLE    posZ
               )
    BEGIN
     Value ( (mswNASMITH_A_STR_FOCUS, 0.59, 0.49, -0.431),
          (mswNASMITH_B_STR_FOCUS, 0.59, 0.49,  0.0  ) )
    END
```

As the current law of variation has been computed using EMMI focus data (Nasmyth B), this focus offset is 0 for side B but -0.431 mm for side A. This figure has been computed by fitting the focus data obtained with SUSI2 using the same program as before (telFocusFit) but using as input file SCT04.SPC

APPENDICES

APPENDIX A

Example and format of log file:
$VLTDATA/ENVIRONMENTS/lt5m1/output/m1Setting.doc

##
97-07-17 14:23:30 ----- Absolute force setting started ----- ZD = 1.0 deg, dZD/dt = 0.0000000 rad/sec
##
An absolute force setting has been started at 14:23:30. At that moment the telescope altitude axis
was at zenith distance 1.0 deg and was moving at a velocity of 0.0000000 rad/sec.

##
97-07-18 00:10:57 ----- Differential force setting started ----- ZD = 24.9 deg, dZD/dt = 0.0000508 rad/sec
high. 20.9 N, mag. 31.5 N, time 27.8 s, corr. -0.324 N
##
A differential force setting has been started at 00:10:57. At that moment the telescope altitude axis
was at zenith distance 24.9 deg and was moving at a velocity of 0.0000508 rad/sec.
The highest force change is 20.9 N, the estimated time for correction is 27.8 s and the correction to compensate for the motion of the telescope amounts to -0.324 N.

##
97-07-17 15:26:13 SET: 1 par (19.7 sec), 0 seq (0.0 sec) | | 12 act, 1.4 N, 0.96 iter. | highest: 23.2 N,
err. delay: -0.021 sec, 5 worst act.: 7, 29, 50, 51, 58, err. sum: -53.8 N, act. lim: 0
fixed points: errors (7,29,50) = 46.5 N, 37.6 N, 16.2 N | current (722.4, 748.6, 764.6)
##
At 15:26:13, a force setting just finished. This force setting is characterized by the following parameters:
- 1 parallel setting performed in 19.7 sec
- 0 sequential setting performed in 0,0 sec
- 12 actuators had a residual error higher than specification (given in database: actAccurSpec = 2.0 N)
- the average of the residual errors on all actuators (except fixed points) was 1.4 N
- the average number of iteration done (meaningful only if sequential setting used)
- the highest residual error (except fixed points) was 23.2 N
- the difference between the duration that actuator with largest force error had to be moved and the duration it has been really moved is -0.021 sec (indicator to check if the parallel force setting went fine and that should be smaller than 1 second).
- the 5 actuators (fixed points included) having the largest force err

Example and format of log file:
$VLTDATA/ENVIRONMENTS/lt5m1/output/actPerformance.log

1 176 848.44 1782.73 4.82 2.10
2 176 833.16 1801.92 4.73 2.16
3 176 1992.25 3967.85 11.32 1.99
4 176 2015.72 3928.36 11.45 1.95
5 176 2052.25 3951.56 11.66 1.93
6 176 2109.42 4033.74 11.99 1.91
7 -1 0.00 0.00 0.00 0.00
8 176 852.34 1737.48 4.84 2.04
.
.
.
76 176 1383.13 2996.10 7.86 2.17
77 176 1373.11 2646.14 7.80 1.93
78 176 1627.70 2585.12 9.25 1.59
82
174
6611.55
2.12
80.63
98-11-29 18:32:54
98-12-16 18:57:23

```
# The information contained in file actPerformance.log concern the M1 actuators.
#
# The meaning of those numbers is the following:
#
#  -> First 78 rows:
#              1st column: actuator number
#              2nd column: number of times this given actuator has been switched on
#              3rd column: cumulated time during which the actuator motor has been moving
#              4th column: cumulated force change (in N) taking only into account the force change
#                          of iteration 1.
#              5th column: average duration of an actuator motor motion (3rd column/2nd column)
#              6th column: effective temporal gain ( = 4th column / 3rd column)
#
#  -> next 5 numbers:
#     1st number: number of force setting done
#     2nd number: number of iteration done
#     3rd number: cumulated time spent setting M1 forces
#     4th number: average number of iteration per force setting
#     5th number: average duration of a force setting
#
#  -> and finally two dates:
#      1st date: time when data logging has started.
#      2nd date: time when last logging has been performed.
```

Example and format of log file:
$VLTDATA/tmp/aoActivties.log

```
98-11-30 00:22:18 RECALC NA 55.9 221.2 91.0 0.0 55.2 261.9 0.0
          15507 -100 2142 0 191 173 410 0 449 174 284 111 174 -105
          15507 -152 2142 0 191 121 410 0 1392 136 284 -44 174 48
          15507 -152 2142 0 191 121 410 0 1392 136 284 -44 174 48
          13.81 14.16 13.74 38 0.3 249.0 0.590 0.490 -3.351
          -1.00 11.9 16.10 1189 247 414   0.18
98-11-30 00:22:18 AVERAGE 0.60 0.01 0.12 0.49 0.18 0.08   0.54
          15212 -155 1418 0 59 -160 614 0 1168 143 316 17 111 15
98-11-30 00:22:38 CORM2 DIFFERENTIAL 0.011 0.030 -0.136
98-11-30 00:22:38 CORM1 DIFF,  -32.4  -32.4   74.8   74.8   74.8
```

```
# The information contained in file aoActivities.log concern the active optics system in general.
#
#
#--date--RECALC NasmFocus,alt,az,rotAng,rotOffs,gpx,gpy,defOffs
#    tilt(M+A),def(M+A),coma(M+A),spher(M+A),ast(M+A),tri(M+A),quad(M+A) raw LCU
#   tilt(M+A),def(M+A),coma(M+A),spher(M+A),ast(M+A),tri(M+A),quad(M+A) inst. aberr. added
#    tilt(M+A),def(M+A),coma(M+A),spher(M+A),ast(M+A),tri(M+A),quad(M+A) in M1 reference
#    TempM1,TempNearM1,TempSerr,hum,windsp,windir,M2posX,M2posY,M2posZ
#     seeing,guideStarMag,TempOutside,maxPixel,backg,numPair, resRms
#--date--AVERAGE d80Def,d80Coma,d80Spher,d80Ast,d80Tri,d80Quad,d80Tot
#   tilt(M+A),def(M+A),coma(M+A),spher(M+A),ast(M+A),tri(M+A),quad(M+A) average in M1 ref.
#--date--CORM1 typeForce force[1] force[2] force[3] .........
#--date--CORM2 typeForce M2MotX M2MotY M2MotZ
#
#
# Explanation of names used to described each element:
# date          -> day - hour - minute - second
# NasmFocus     -> Nasmyth focus (NA or NB)
# alt           -> altitude (deg)
# az            -> azimuth (deg)
# rotAng        -> rotator angle (deg)
# rotOffs       -> rotator offset (deg)
# gpx           -> X coordinate of guide probe position (mm)
# gpy           -> Y coordinate of guide probe position (mm)
# defOffs       -> defocus offset (nm)
#
# tilt(M+A)     -> modulus and angle of tilt (nm) + (deg)
# def(M+A)      -> modulus and angle (=0) of defocus (nm) + (deg)
# coma(M+A)     -> modulus and angle of coma (nm) + (deg)
# spher(M+A)    -> modulus and angle (=0) of spherical aberration (nm) + (deg)
# ast(M+A)      -> modulus and angle of astigmatism (nm) + (deg)
# tri(M+A)      -> modulus and angle of triangular coma (nm) + (deg)
# quad(M+A)     -> modulus and angle of quadratic astigmatism (nm) + (deg)
#
# TempM1        -> M1 temperature (deg)
# TempNearM1-> near M1 temperature (deg)
# TempSerr      -> Serrurier temperature (deg)
```

```
# hum         -> humidity (%)
# windsp      -> wind speed (m/s)
# windir      -> wind direction
# M2posX      -> M2 position along X axis (mm)
# M2posY      -> M2 position along Y axis (mm)
# M2posZ      -> M2 position along Z axis (mm)
#
# seeing      -> seeing (arcsec)
# guideStarMag-> guide star magnitude (mag)
# TempOutside-> outside temperature (deg)
# maxPixel    -> maximum pixel value in the SH image
# backg       -> background measured in the SH image
# numPair     -> number of spot pair found
# resRms      -> residual rms
#
# d80Def      -> contrib. of defocus to the diameter containing 80% of light (arcsec)
# d80Coma     -> contrib. of coma to the diameter containing 80% of light (arcsec)
# d80Spher    -> contrib. of spher. aberr. to the diameter containing 80% of light (arcsec)
# d80Ast      -> contrib. of astigmatism to the diameter containing 80% of light (arcsec)
# d80Tri      -> contrib. of tri. coma to the diameter containing 80% of light (arcsec)
# d80Quad     -> contrib. of quad. ast. to the diameter containing 80% of light (arcsec)
# d80Tot      -> total contrib. except def. to the diameter containing 80% of light (arcsec)
#
# typeForce   -> type of correction applied (ABS or DIFF)
# force[1]    -> force in N on actuator #1 (variation or absolute)
# force[2]    -> force in N on actuator #2 (variation or absolute)
# force[3]    -> force in N on actuator #3 (variation or absolute)
#
# M2MotX      -> M2 position in mm along X axis (variation or absolute)
# M2MotY      -> M2 position in mm along Y axis (variation or absolute)
# M2MotZ      -> M2 position in mm along Z axis (variation or absolute)
```

APPENDIX B

Template for side A field astigmatism mapping

Nasmyth focus: A
================

Date:

Starting time:	Outside seeing:	Star magnitude:
GP coordinates: 167.3 166.9	Tel. offsets: 0.0 , 0.0	Rot: 0
GP coordinates: 167.3 16.9	Tel. offsets: -804.8 , 60.8	Rot: 0
GP coordinates: 61.2 60.8	Tel. offsets: 278.5 , 551.5	Rot: 0
GP coordinates: 17.3 166.9	Tel. offsets: 587.1 , 192.5	Rot: 0
GP coordinates: 61.2 273.0	Tel. offsets: 551.5 , -278.5	Rot: 0
GP coordinates: 167.3 316.9	Tel. offsets: 192.5 , -587.1	Rot: 0
GP coordinates: 61.2 60.8	Tel. offsets: -278.5 , -551.5	Rot: 180
GP coordinates: 17.3 166.9	Tel. offsets: -587.1 , -192.5	Rot: 180
GP coordinates: 61.2 273.0	Tel. offsets: -551.5 , 278.5	Rot: 180
GP coordinates: 167.3 166.9	Tel. offsets: 612.3 , 526.3	Rot: 180
GP coordinates: 167.3 166.9	Tel. offsets: 0.0 , 0.0	Rot: 0
Finishing time:	Outside seeing:	

Template for side B field astigmatism mapping

Date:
Starting time: Outside seeing: Star mag.:

GP coordinates: 167.7 161.7	Tel. offsets: 0.0 , 0.0	Rot: 0
GP coordinates: 167.7 11.7	Tel. offsets: -804.0 , -47.8	Rot: 0
GP coordinates: 61.6 55.6	Tel. offsets: 201.5 , 582.7	Rot: 0
GP coordinates: 17.7 161.7	Tel. offsets: 554.7 , 269.1	Rot: 0
GP coordinates: 61.6 267.8	Tel. offsets: 582.7 , -201.5	Rot: 0
GP coordinates: 167.7 311.7	Tel. offsets: 269.1 , -554.7	Rot: 0
GP coordinates: 61.6 55.6	Tel. offsets: -201.5 , -582.7	Rot: 180
GP coordinates: 17.7 161.7	Tel. offsets: -554.7 , -269.1	Rot: 180
GP coordinates: 61.6 267.8	Tel. offsets: -582.7 , 201.5	Rot: 180
GP coordinates: 167.7 161.7	Tel. offsets: 534.9 , 602.5	Rot: 180
GP coordinates: 167.7 161.7	Tel. offsets: 0.0 , 0.0	Rot: 0

Finishing time: Outside seeing:

APPENDIX C

##
In this file should be registered all actions
(mechanical or electrical) executed on any of the
M1 actuators.
For each action, the following information should
be given:
- date
- name of the person(s)
- actuator number(s)
- nature of the action
##

Date	Name	Actuator #	Action performed
19/08/98	R. Parra	59	Motor changed, lubrification
15/09/98	O. Lavin	59	Mechanics adjusted