VLT ASTRONOMICAL SITE MONITOR: CONTROL, AUTOMATION, AND DATA FLOW

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ABSTRACT

As major observatories are planning automatic and optimized scheduling of large astronomical facilities, reliable and accurate monitoring of observing conditions is a pre-requisite. For this purpose, the concept of ***Astronomical Site Monitor (ASM)*** has been developed for the VLT as an integrated sub-system of the observatory.

The ASM runs in automated mode and provides the control software of the VLT unit telescopes with measured environmental data, including outside seeing and meteorological parameters. The VLT common software and standardized hardware components have been adopted throughout the system. The ASM is therefore a good example for the portability of the VLT standard components, leading to increased reliability and easier maintenance.

Two almost identical ASM systems are now in operation at the Paranal and La Silla observatories. The system attributes, results, and future extensions will be described.

Keywords: ESO, VLT, ASM, weather, seeing, site monitor, automated system, telescope scheduling, telescope control

1. INTRODUCTION

The ASM provides the observatory with indispensable data about the environment, weather parameters and outside seeing in particular. This information is then used in various ways:

- Astronomers and telescope-operators can decide about operational conditions and optimal use of the telescope.
- The telescope control software (TCS) automatically adjusts internal parameters e.g. for tracking and cooling.
- It is archived together with scientific frames in order to record environmental conditions during an observation.
- It is injected into a long-term database, that can be queried at any time, and builds the basis for weather prediction.
- It makes automatic scheduling of observations possible.

The La Silla observatory already had a site-monitor facility for about ten years. During the specification phase of the ASM for the VLT Paranal observatory it was then decided to build a system that uses as much as possible “VLT-standard” components for hardware and software, with the objective of easier maintenance and improved reliability. However, some core elements of the existing systems were upgraded, adapted where necessary, and re-used. In the end, two twin-brothers should exist on both observatory sites. The history of the ASM development can be summarized as follows:

- 1997: Design and implementation of the control software and hardware.
- Mid 1997: Installation and subsequent test phase of the new system at La Silla, in parallel to the old one.
- Beginning 1998: Transport from La Silla to Paranal, installation and commissioning, then regular operation.
- Beginning 1999: Decommissioning of the old La Silla system, then upgrade to the same status as Paranal.
- March 1999: Re-integration of the La Silla system, with subsequent test phase, then regular operation.

This paper concentrates on the control software for the ASM, but touches also other related aspects.

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2. SYSTEM OVERVIEW

The two installed ASM systems at Paranal and La Silla are identical, except minor differences in the hardware interfaces. The core component is the ***Differential Image Motion Monitor (DIMM)*** [1] for seeing measurement, which is a 35-cm telescope with a technical CCD detector mounted at its cassegrain focus, located on a 5 to 6 meter high tower with enclosure. In addition, an automatic weather station manufactured by VAISALA collects the data from several sensors, which are mounted on a 30 meter high mast.

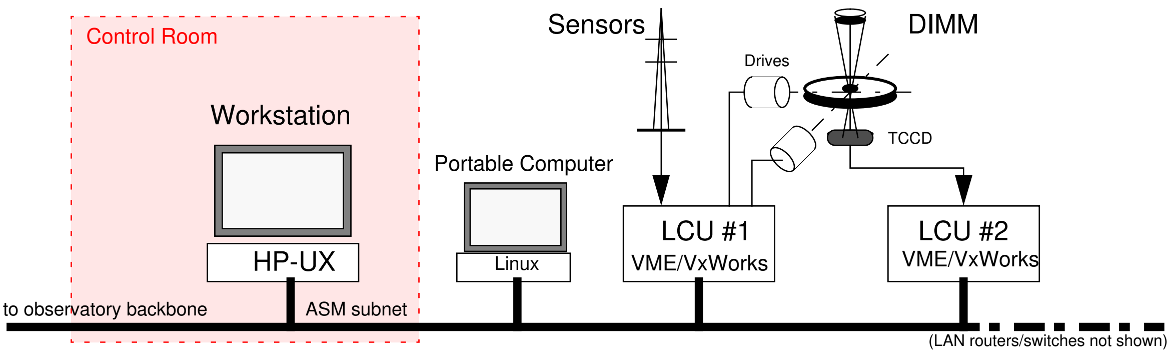
Figure 1: The DIMM tower at La Silla - Meteo mast and DIMM tower on Paranal

The complete control system consists of:

- A Hewlett-Packard C-110 or C-200 workstation for coordination, short-term data storage (~1 day) and display.
- The DIMM with telescope and technical CCD detector for seeing measurement.
- Several external sensor units, incl. the Vaisala weather station (Milos 500 respectively 200 models).
- Two Local Control Units (LCU) controlling the DIMM and external sensor units (with real-time requirements).
- An optional portable computer for alignment, test and maintenance.

The components are interconnected with ethernet, and then - via router - to the backbone network of the observatory.

Figure 2: ASM components overview



The whole system operates unattended by any operator, thus the DIMM constitutes a “robotic telescope”, opening and closing automatically, selecting target starts, and delivering seeing data to its customers. The weather data is based on permanent cyclical reading of the variety of sensors and calculation of derived data. The ASM database contains and provides the latest value of all measured variables, which are also saved periodically (typically every minute) into the VLT on-line archive.

The following sections present the general properties of the ESO site monitors together with some historical facts.

2.1 THE ASM OF THE PARANAL OBSERVATORY

- Location: Cerro Paranal, 2635 m (2664 m before levelling) 70 24' 5" W; 24 37' 24" S, Distance from coast: 12 km

The Vaisala meteorological station was installed in Paranal in October 1984 and upgraded in June 1998. It includes, on a 30 m high mast, a number of sensors. The following measurements are provided:

- 30 m level: Wind speed and direction, Temperature, Humidity, Particle Count
- 20 m level: Wind speed (three-dimensional), Particle Count
- 10 m level: Wind speed and direction
- 2 m level: Temperature and Humidity, Barometric pressure

The ESO seeing monitor (DIMM1) was installed in April 1987, at the northern edge of the summit, and replaced by a more modern copy (DIMM3) in September 1990. Measurements were suspended in July 1991 for the 14 months duration of the levelling work. Seeing has been then monitored during the construction period of the VLT observatory with few interruptions. Finally, DIMM3, upgraded to VLT standards and fully automatized was re-commissioned in August 1998 as part of the VLT Astronomical Site Monitor. Measurements are taken 6 m above ground.

The meteorological station computes and stores average, root mean square and extrema of each parameter during preset averaging periods (1 and 20 minutes). The sampling intervals are 2 seconds for digital sensors (pressure, wind speed and direction) and one minute for analog sensors (Temperature, Humidity). One and twenty minute averages are ingested into the database (compared to only 20 min at La Silla).

The seeing is defined as the Full Width Half Maximum (FWHM) of a stellar image observed with a perfect large telescope, at 500 nm wavelength and at zenith. It is measured over periods of about a minute all night long. Maximum wind speed for operation is about 18 m/s and sky must be clear in the zenith area.

Approximate values for the resolution of the various weather sensors, applying for Paranal and La Silla, are the following:

- Wind direction: 5.63 deg (threshold: 0.3 m/s)
- Wind speed: accuracy ~2% over 10 m/s (threshold: 0.4 m/s)
- Temperature: accuracy ~0.1 deg
- Humidity: linearity about 1%
- Seeing: better than 10% above 0.25 arcsec

2.2 THE ASM OF THE LA SILLA OBSERVATORY

- Location: Cerro La Silla 2400 m; 70 42' W; 29 16' S, Distance from coast: 40 km

The Vaisala meteorological station was installed at La Silla in February 1985, it includes, on a 30 m high mast, a number of sensors. The archive database started storing data on January 1st, 1994. The following measurements are provided:

- 30 m level: Wind speed and direction
- 2 m level: Temperature, Humidity, Barometric pressure

The ESO seeing monitor (DIMM2) was installed in March 1991, on a 5m high tower, close to the Schmidt telescope as part of the permanent Astronomical Weather Station (AWS). Routine operation started in September 1991 and full automation was reached in December 1993. The old seeing monitor was then decommissioned beginning of 1999 and upgraded to the Paranal status. Operation has been resumed in April 1999.

The meteorological and seeing data are defined as before.

3. The ASM Control Software

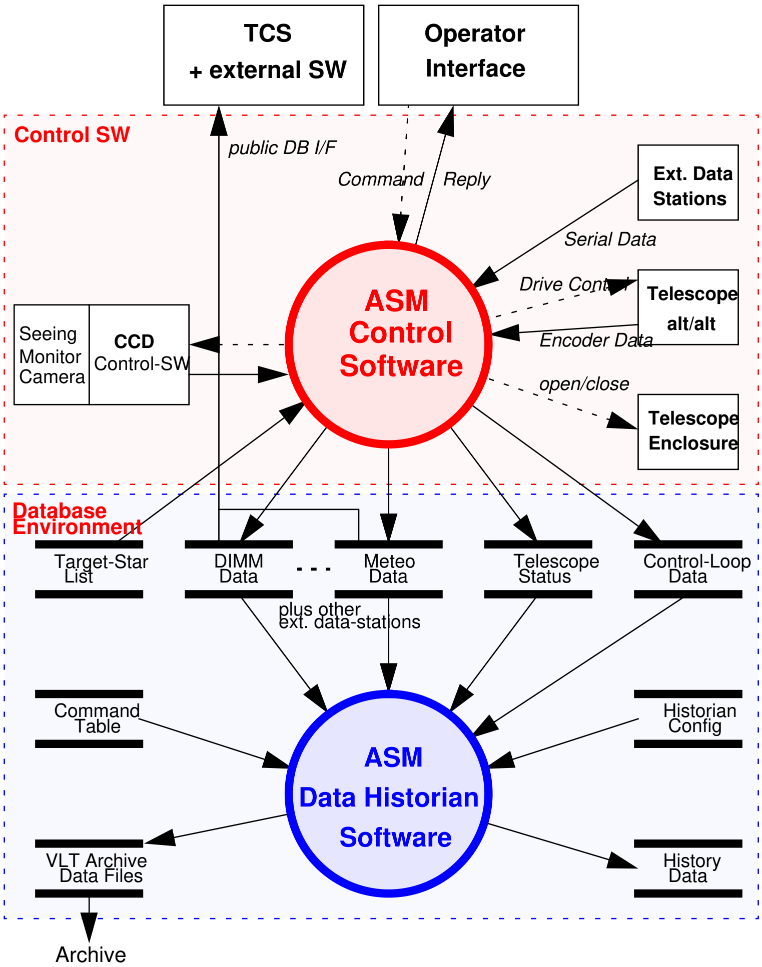
The ASM control software has been developed in the framework of standards established by the VLT common software:

- C++ code, object-oriented and event-driven programming on the (non-real-time) Unix workstation side
- C code on the real-time VxWorks LCU side (no C++ support available at the time of design and implementation)

The package consists presently of 14 modules, each one either dedicated to the control of a subsystem or a global purpose; in total they contain approximately 80.000 lines of code. A clear dependency hierarchy between modules has been established, and identified features that are needed by more than one subsystem have been extracted to common modules for easier maintenance. Beside that, several modules of the VLT Telescope Control System (TCS) are being used, as well as most of the VLT common software release, including the CCD control software that incorporates some image analysis features that are exclusively needed for the ASM-DIMM. All modules are under strict configuration control, as for other VLT software. This avoids any inconsistency of software-module versions in the system, and allows to build the whole system from scratch on an "empty" workstation.

The diagram below shows the structure of the ASM software [3].

Figure 3: ASM Software Diagram



The *ASM Control Software* block represents the functionality to control external hard- and software, and to provide the on-line data. It consists of real-time LCU parts as well as workstation parts. The *ASM Data Historian Software* includes functionality to produce data for the VLT on-line archive and internal history data for second-level processing of the on-line data. It is mainly located in the workstation environment.

3.1 Usage of VLT-standard Architecture and Components

A very important aspect in the design of the ASM is the use of standardized hardware and software components, that are applied everywhere in the VLT control system:

- Workstation running HP-UX and installed with the VLT common software release incl. GNU tools, Tcl/Tk, Rtap
- LCU hardware with VMEbus systems and ESO-standardized boards, running VxWorks and VLT common software

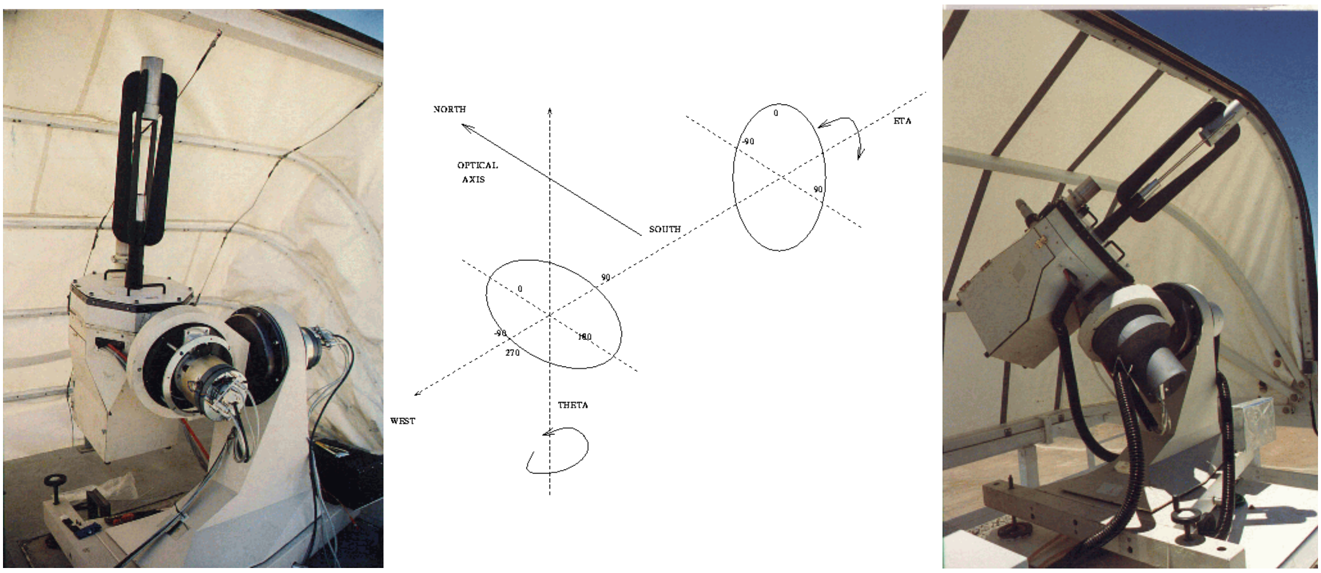
All basic concepts of the VLT common software are applied throughout. Consequently the command interface looks similar as for the VLT unit telescopes and instruments. More specifically, the ASM control software uses some of the same modules as for the control system of the VLT unit telescopes: The DIMM telescope moves according to the coordinates provided by the VLT tracking module, including the SLALIB [7] positional astronomy library and TPOINT [8] based pointing solution; the two telescope axes are controlled by the same position controller software module; the on-line archive interface uses the same mechanism; and so on.

When a new VLT common software release becomes available, it will normally be installed on the ASM, therefore propagating all included error corrections and feature extensions. Thus the system reliability should increase even without maintenance activities on the ASM software itself.

3.2 DIMM Telescope Control

The DIMM telescope, designed by AMOS SA, Belgium, has an alt/alt mounting type ($\eta-\theta$, eta-theta coordinates). When receiving a new RA/Dec reference position, the telescope will preset with the help of a pointing solution to the target star, center it on the CCD, and follow it supported by auto-guiding until a limiting hour-angle is reached.

Figure 4: The DIMM telescopes at La Silla (left) and Paranal (right), eta/theta coordinate definitions (middle)



Due to mechanical constraints of the telescope mount, the operating range is limited to only one half of the sky (north or south). One can track only slightly over the limits of a half-sky (“behind” the zenith). For simplicity, we have restricted the normal pointing and tracking range to the southern half-sky, i.e. the DIMM will never see a star in the north. Otherwise time-consuming “flip-over” operations to the opposite half-sky would be necessary, and the construction of the cable-wraps would become more complicated. Also the control software supports presently only the southern range.

Both telescope axes are driven by DC motors over a transmission unit. Incremental rotary encoders (Heidenhain ROD, 1000 lines) are mounted at an intermediate stage with 520:1 transmission factor; in order to obtain the absolute position they must first be initialized after power-up by moving to the limits. Each axis is controlled by an analog PI velocity controller implemented in hardware, and a cascaded digital software-based position controller with switchable characteristic (PI near the set-point), the same as used in other VLT systems.

Also the same tracking software (trk) as for the VLT unit telescopes is used here. Given the RA/Dec target position and an accurate absolute time reference as input, this calculates position references in alt/az coordinates (az is defined counter-clockwise with zero at south) as output, and therefore a conversion to eta/theta is necessary to obtain the proper axis set-points. This is accomplished by several matrix operations. In the general case for arbitrary rotation angles around the North-South (a), East-West (b), and vertical (c) axis we have:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(a) & \sin(a) \\ 0 & -\sin(a) & \cos(a) \end{bmatrix} \bullet \begin{bmatrix} \cos(b) & 0 & -\sin(b) \\ 0 & 1 & 0 \\ \sin(b) & 0 & \cos(b) \end{bmatrix} \bullet \begin{bmatrix} \cos(c) & \sin(c) & 0 \\ -\sin(c) & \cos(c) & 0 \\ 0 & 0 & 1 \end{bmatrix} \bullet \begin{bmatrix} \cos(az) \cdot \cos(alt) \\ \sin(az) \cdot \cos(alt) \\ \sin(alt) \end{bmatrix} \qquad (1)$$

Although freely configurable in the software, we assume normally the ideal case for the rotation angles with respect to the alt/az system of a = 90°, b = 0°, c = 180°, so that the equation is simplified to:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix} \bullet \begin{bmatrix} \cos(az) \cdot \cos(alt) \\ \sin(az) \cdot \cos(alt) \\ \sin(alt) \end{bmatrix} \qquad (2)$$

For the southern half-sky, eta and theta are then calculated and normalized to:

$$\eta = \operatorname{atan}\left(\frac{y}{x}\right) - \pi \qquad \eta < 0 \qquad (3)$$

$$\theta = \pi - \operatorname{atan}\left(\frac{z}{\sqrt{x^2 + y^2}}\right) \qquad \frac{\pi}{2} < \theta < \frac{3\pi}{2} \qquad (4)$$

Similarly, the pointing solution implemented in the trk module only supports the alt/az-specific terms of the TPOINT software. Although this is generally sufficient for our purposes, it implies problems in the zenith area (the singularity for an alt/az telescope) due to inappropriate modelling and resulting high distortion compared to the uncorrected trajectory. Since the DIMM is preferably tracking near - or even through - the zenith, it is supported and normally necessary to disable the pointing correction during tracking and use it only for presetting. The determination of a pointing model is a maintenance operation that normally has to be done only once at installation time, given stable mechanics and the absence of major earthquakes. Several tools are provided with the ASM control software to facilitate this operation. The pointing terms are calculated with TPOINT.

As a backup solution in case of insufficient pointing accuracy, a spiral search algorithm has been implemented into the ASM software as well. Descriptively named “Snoopy-Mode”, this comes into action when no star is found in the field after presetting, and will offset the telescope in steps of slightly less than the field size in a spiral-like motion, until a target star is found (which is most certainly the one we are looking for, since we are dealing with magnitudes < 3). Fortunately it has been shown that with a good mechanical alignment and a properly determined pointing model the DIMM will hardly ever use this feature.

Good pointing accuracy is only critical in the south-east sky quadrant, since the DIMM will normally preset to a new target star in this area, and follow it afterwards with the help of the auto-guider. Pointing models are therefore normally determined exclusively with stars of this part of the sky, improving the accuracy in this area while neglecting the less important other parts.

For auto-guiding, x/y offsets are determined from the centroid of the CCD image, passed through a PI controller, and added to the position references from trk after conversion, before they are forwarded as set-points to the axis control loops. Field rotation is not present in this mounting type, therefore the x/y error vectors derived from the centroiding can be forwarded directly as eta/theta offsets. To compensate wind-shake, error-vectors are averaged over several images.

The DIMM enclosure consists of a north- and south-half shell, that can be opened and closed independently. Normal operation foresees only fully opened or closed positions. The devices are designed by Halfmann Teleskoptechnik, Germany, for Paranal, respectively by ESO La Silla.

The tower, on which the DIMM and its enclosure are resting, is for Paranal a 6 meter high metal construction designed by the Observatory Capodimonte, Italy, and for La Silla a 5 meter high concrete tower designed by ESO.

3.3 DIMM TARGET STAR SELECTION

The ASM-DIMM target-star list contains a small number of objects that are used as target positions for the telescope. Objects can be individually disabled for automatic selection if they are not suitable, e.g. outside of tracking range, too bright or too faint. The list may contain stars of both half-skies, but due to the mechanical restriction of the telescope mount (see 3.2) selection must be restricted to the southern half-sky. The basic criteria for automatic selection are:

- minimize the number of changes of a target-star ⇒ select star with hour-angle closest to a starting reference (e.g. -3 h)
- maximize brightness ⇒ select star with highest (most negative) magnitude M

When a new target is to be selected, the selection algorithm proceeds over the list and first discards the unsuitable ones:

- Brightness too small: $M > M_{max}$
- Airmass too high: $A > A_{max}$
- Hour-angle greater than the maximum tracking hour-angle: $H > H_{max}$

The tracking range is normally configured to hour-angles between -3 and +3 h, and airmass below 2. After this exclusion, a criterion function is evaluated for each enabled star in the list:

$$z = P_H \cdot \frac{|H - H_{ref}|}{\pi} + P_M \cdot \left(\frac{M}{2 \cdot M_{max}} + 0.5\right) \tag{5}$$

with the configuration parameters P_H (priority hour-angle), P_M (priority magnitude), H_{ref} (reference hour-angle), M_{max} (maximum magnitude). The star with the lowest value of z will then be selected.

There is a mechanism to disable a star temporarily from selection whenever centering on this star failed (e.g. when the sky is partly cloudy), or the seeing measurement sequence could not be performed on this star. All temporary disable flags will be removed if at some point no star passes the selection anymore.

3.4 DIMM IMAGE PROCESSING PROCEDURES

The ASM is equipped with a frame transfer CCD detector of 400 · 290 pixels. The observation wavelength is 500 nm, the pixel size 22µm and scale 0.864 arcsec. The CCD can be operated in full frame with or without binning or in one or two window mode. For the real-time image processing, it is possible to define the location and size of the area included in the readout window to be processed, thus eliminating any possible artifacts due to the readout. The processing is performed sequentially on the windows. The following operations can be performed on the data as part of the CCD control software [6]:

1. bias subtraction from an external bias image
2. flat-field correction also from an external flat-field image
3. image statistics comprising:
   - estimation of the image background as the average of the three less illuminated corners of the image, associated with its standard deviation (*backGnd* and *backGnd_SD*)
   - computation of the threshold as a multiple of the standard deviation of the background ($thrMin = n \cdot backGnd\_SD$)
   - image statistics: extrema *min*, *max* and *location*, average *flux/pixel* and its standard deviation *flux_SD*, and number of valid pixels satisfying $(P_{i,j} - backGnd) >= thrMin$
4. estimation of the centroid C of the image (thus the error vector E to a given reference pixel R)
5. invoke an external *user-function* for additional application dependent processing and synchronization

3.4.1 TARGET STAR CENTERING AND AUTO-GUIDING

At preset completion, the CCD is activated in full frame mode so as to detect the star in the field. The image is first corrected for the bias (equivalent to a dark) to eliminate the hot pixels that might influence the detection. The image is re-centered on the reference point by sending offset corrections to the telescope axes. This procedure is repeated until the star is within the auto-guider target radius (typ. 5 arcsec).

During the measurement sequences, the auto-guider is activated that sends offsets to the telescope axes to correct for low frequency wind shake and tracking inaccuracy. Typically one correction every 30 images in DIMM mode is sent. The offsets are processed by a PI-controller.

3.4.2 SEEING MEASUREMENT SEQUENCE

The CCD is activated in 2-window mode with typ. exposure time 5 ms, window size $40 \cdot 40$. The sequence consists of the acquisition of 800 exposures every minute. The windows are located in a hot pixel free area of the chip in order to avoid the bias correction. The threshold is set to ($9 \cdot$ *backGnd_SD*) for the determination of the centroid; it ensures that all pixels acquired on the sky are set to zero, thus not biasing the centroid. It is also the only reliable and fast discrimination criterion for the detection of the object in the window. Consequently, the centroid is invalid whenever the image of the star does not emerge out of the background, yielding not to deliver erroneous data.

The ASM-specific user function then collects and reduces the data obtained on each spot including validation, estimation of the signal-noise ratio, FWHM, etc. [4]. At completion of the sequence the reduced data is processed on the workstation where seeing, scintillation, etc. are computed [2] and made available in the database to the observatory.

3.4.3 COHERENCE MODE MEASUREMENT SEQUENCE

The CCD detector is operated taking full advantage of the frame transfer mode since two vertical windows are defined of 31 pixel width and full height of 290 lines of the chip. Typically 10 integrations are performed per exposure: integrate 1 ms, then shift the charges down of 29 rows (shift time 125 µs) so that the whole frame is located in the cache and is readout without frame transfer. The sequence consists typically of 100 exposures acquired in ca. 1 minute. On each of these stripes statistical data and centroid are computed as described above. It yields an array of 10 time-stamped data blocks for each column. Since the time between 2 stripes is well determined, it is possible then to derive the image velocity in both directions, thus the wavefront. This mode has been implemented on the CCD control software to demonstrate its feasibility. Full implementation of the data reduction flow is planned.

3.5 FUTURE EXTENSIONS

The ASM remains under development, and it is planned to add some further units to the Paranal, and partly also La Silla systems. The purpose of these on-going projects are briefly described as follows.

- *Extinction Monitor*: to provide an extinction measurement in the line-of-sight of the DIMM telescope, based on photometric analysis of the target star in parallel to the seeing measurement sequence.
- *Coherence Monitor*: to estimate or even forecast the wavefront temporal characteristics in real-time; as described above, the DIMM CCD can be used in a special mode in order to determine the wavefront velocity from the resulting image data. This mode can be interleaved with the seeing measurement sequence, and thus no further hardware is required.
- *All Sky Imager*: to detect and locate all types of clouds, to establish sky brightness maps during moonlight nights, and to determine the extinction during photometric nights. It requires an additional CCD detector assembly.
- *Seismic Monitor*: to record (micro-)seismic events as required by the VLT interferometer at Paranal, but also to establish a general-purpose earthquake detection system at the observatory site.

4. AUTOMATED OPERATION

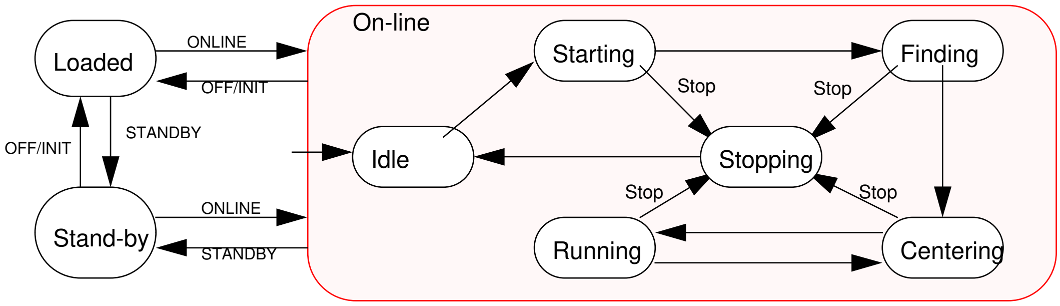
The ASM is designed as a completely automated system. For this purpose the various subsystems are coordinated by a central process, running on the ASM workstation. This process checks for the sun position to switch between day-time (stand-by) and night-time (on-line) states, which are defined as follows:

Table 1: ASM Operational States

On-line (default night-time state)	Stand-by (default day-time state)
Enclosure open	Enclosure closed
Telescope presetting or tracking	Telescope idle, optionally in park position
Target star selection enabled	Target star selection disabled
DIMM CCD taking exposures	DIMM CCD idle
Meteo and other external sensors enabled	Meteo and other external sensors enabled (no difference)

While in On-line state, the control process also takes care of target star selection, telescope presetting, object centering, auto-guiding, and seeing measurement. In parallel it performs the checks for operational limits (meteo alarms for high wind speed or humidity), and puts the system to a safe Stand-by state whenever necessary.

Figure 5: ASM control process state diagram

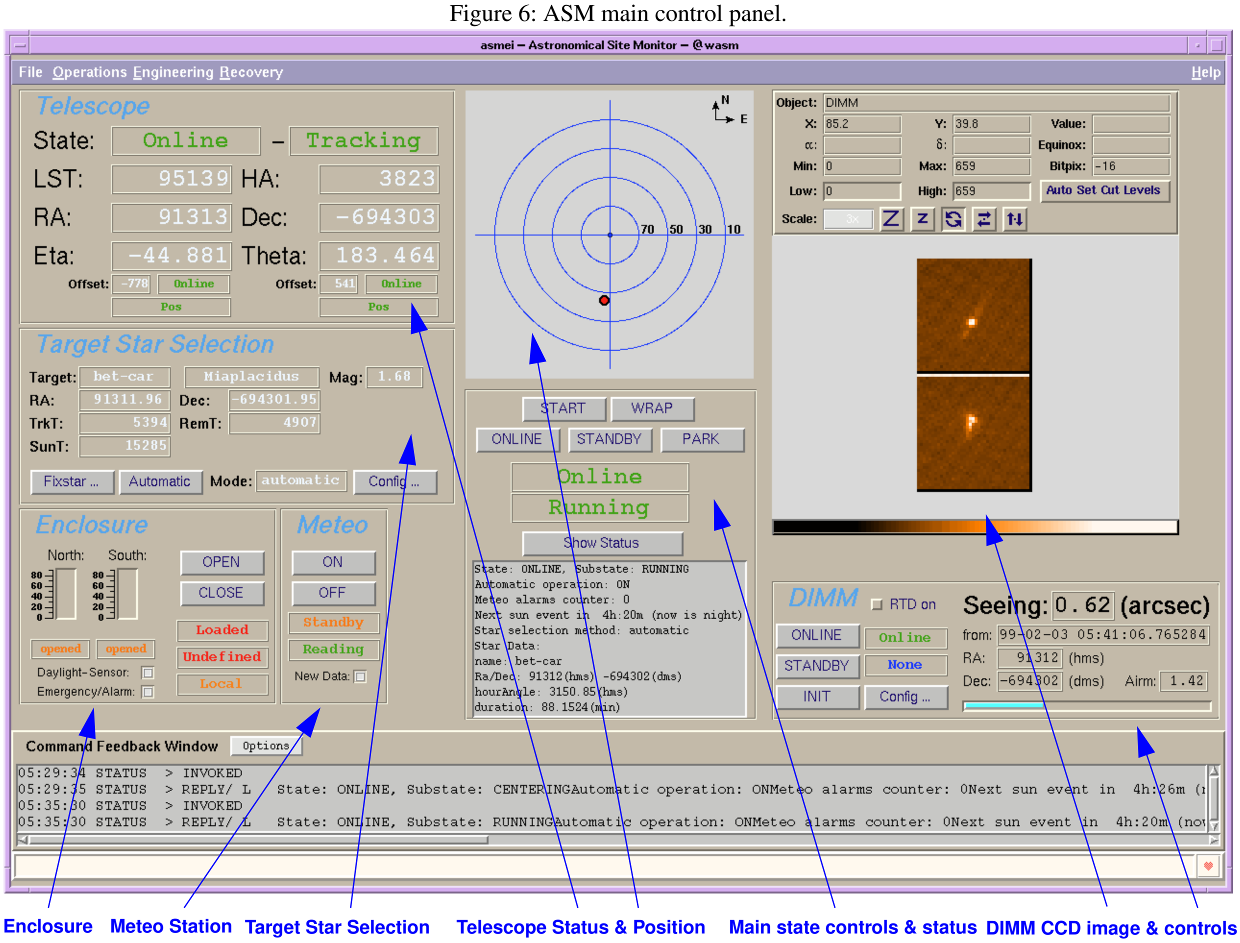


The On-line state consist of several sub-states:

- Starting: when entering on-line operation, all sub-systems are being brought to on-line state
- Finding: a new target star is selected and the telescope being preset
- Centering: after preset is completed, the target is being centered on the detector
- Running: after the target is centered, the seeing measurement sequence is being performed
- Stopping: at end of on-line operation, all sub-systems are being brought to stand-by state

Interactions with the system are normally not necessary during automatic operation. The ASM "operator" panel is therefore mainly intended for status monitoring rather than giving commands (what is anyway possible for maintenance and test). The panel is shown below.

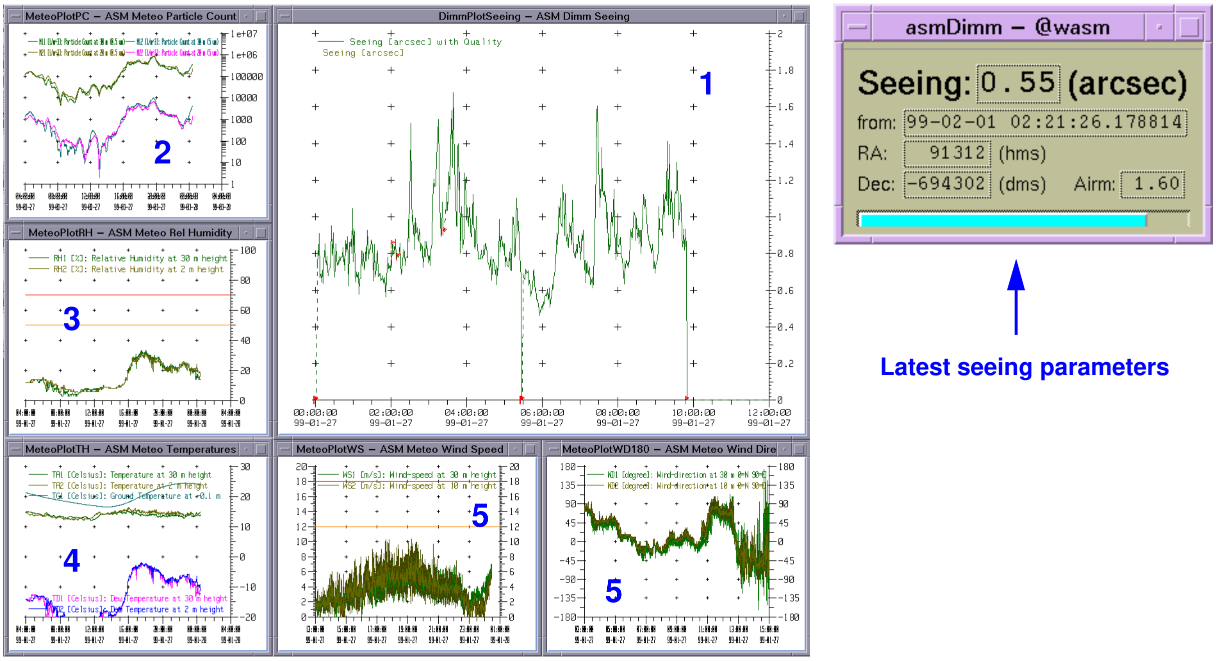
Figure 6: ASM main control panel.



5. ASM Data Displays for Astronomers and Operators

The data that ASM provides are presented to telescope operators and astronomers in form of plots and numerical data panels [5]. The plotting facility of Rtap is extensively used here. A typical ASM data screen includes trending plots for seeing, wind speed and direction, temperatures and humidity in different heights. It looks like this:

Figure 7: A typical ASM data screen



In detail, the most important available data plots are:

1. *Seeing*: This plot shows the seeing curve over the night. While the DIMM cannot deliver new data, e.g. when the telescope presets to a new target star or during bad weather conditions when the DIMM must close, the plotted curve is forced to zero.
2. *Particle Count*: This plot shows in four curves the particle count (dust) in 20 and 30 m height, for particles of 5 and 0.5 µm each. The scaling is logarithmic to accomplish a reasonable display over the whole possible range.
3. *Relative Humidity*: Relative humidity is measured in two heights for Paranal. La Silla provides only one value. Limit lines (here at 50% and 70%) are recommendations to close the telescope when the humidity exceeds this value.
4. *Temperature and Dew-Point*: The air temperature is measured in two heights, with additional ground temperature. The dew point is a calculated value depending on air temperature, humidity, and pressure, and it is indicated to close the telescope when the dew point comes near the temperature of any optical surface, to avoid condensation.
5. *Wind Speed and Direction*: These two plots also indicate the variability in wind speed (gusts) and wind direction as a shaded area. Two curves show the sensor data for 30 and 10 meter height. Limit lines (here at 12 and 18 m/s) are again recommendations to close the telescope when this value is exceeded.

6. ASM Data Interfaces to Telescope and Archive

Some parameters provided by the ASM are used by Telescope Control System (TCS) to automatically correct the reference position of the unit telescopes during tracking, namely air temperature, humidity, and a calculated temperature lapse rate. The enclosure and thermal control part of TCS uses temperature, wind speed and direction to automatically open or close louvers and ventilation doors depending on where the telescope points, or to adjust the cooling reference temperatures inside the telescope. The outside seeing is an essential parameter to compare with the FWHM value that the telescope actually provides during observation, although several rules must be applied to make a fair comparison. For conversion from DIMM to expected observed seeing, the following formula shall be used, dependent on observing airmass A_{obs} and wavelength λ_{obs}

(with $\lambda_{dimm} = 0.5\ \mu m$):

$$FWHM_{obs} = FWHM_{dimm} \cdot (A_{obs})^{0.6} \cdot \left(\frac{\lambda_{dimm}}{\lambda_{obs}}\right)^{0.2} \tag{6}$$

During observation, a telescope instrument will query TCS for the current environmental parameters, which are then stored together with the scientific frames. Furthermore, a subset of the ASM data is directly ingested into the ESO on-line archive. Based on this, a web-based tool is available to display the data of a selected night (ASM Archive Ambient Server, *http://archive.eso.org/asm/ambient-server*).

7. Performance of the Paranal & La Silla Systems

7.1 DIMM Pointing and Tracking

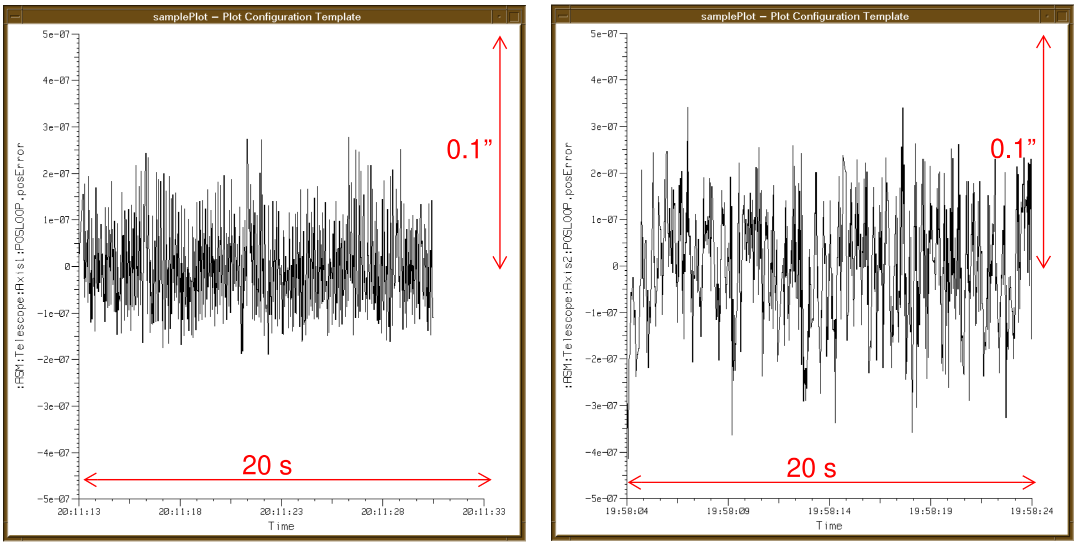
The DIMM has a field of view of approximately 4 arcmin. The maximum pointing error must therefore not be larger than 2 arcmin in either direction. The pointing models determined for the Paranal and La Silla system have shown that this condition can be met, although the stability of the axis drives play a critical role. The Paranal telescope has an high backlash in the gearbox of the eta drive, which cannot be suppressed by the pointing solution, and therefore the pointing performance is much worse than the La Silla system, that is flawless in this respect.

Only target stars in the south-east sky quadrant are taken for the pointing determination. For fitting of the model only alt/az-specific terms of TPOINT are applied.

- La Silla: The raw Sky RMS error is 101.8 arcsec. After fitting the resulting Sky RMS is 19.63 arcsec.
- Paranal: The raw Sky RMS error is 211.5 arcsec. After fitting the resulting Sky RMS is 87.13 arcsec.

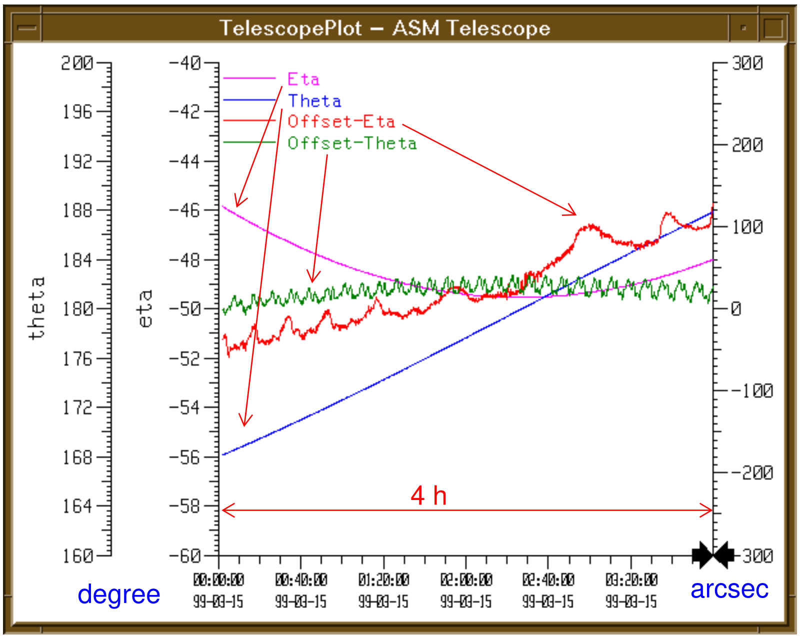
Axis position error during tracking: The tracking speed of eta is dependent from the hour-angle, and consequently the axis position error, measured on the encoder, depends on it (small at the meridian, higher with increasing hour-angles). The tracking speed of theta is always constant. The maximum position error of both axis during tracking stays in all cases well below 0.1 arcsec.

Figure 8: DIMM tracking position error: eta at HA = -1 h (left), theta (right)



Tracking with auto-guiding: The following plot shows the eta/theta offsets over 4 hours (HA -2 to +2) while tracking a star (bet-car, RA 09h13’11”, Dec -69d43’01”) with auto-guiding through the meridian. No pointing model has been used during tracking, but only for presetting. Clearly visible are the periodic errors of the axes of approximately 20 arcsec peak-to-peak, a consequence of the transmission unit between telescope and encoder axes. Since acceptably small, we made no attempt to correct for these with the pointing solution. This result had been expected based on positioning repeatability tests of the axis drives done during design phase in the lab.

Figure 9: DIMM tracking with auto-guiding



7.2 RELIABILITY

The assumption that the on-going development of the common VLT software would improve the over-all software reliability has been proven positively correct. The propagation of every new release to the ASM has indeed decreased software-related downtime, although only minimum software maintenance effort has been spent since mid 1998 on the ASM-specific part. With the current October 1999 release, the software-induced system outage converged to a plain zero for the Paranal system.

Initial problems with the reliability of the common VLT time reference hardware (used by the tracking unit), especially for the La Silla system, could be solved by repair of this unit. The underlying flaw itself had been recognized first with other VLT systems, and the ASM now benefits automatically by its correction. An example that the decision to apply VLT-standard hardware components is also justified.

We will continue to improve the methods and tools to better analyse the system performance in order to detect possible hidden flaws. With a system of such complexity, the aspect of an entirely automated and unattended operation (which is unparalleled by any current VLT software application) was the most difficult task during development. But, after initial problems, the stability has finally reached a very convincing level.

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