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# Table of Contents

# 1 Introduction

## *1.1 Purpose*

This document provides a summary of the Instrument Software Requirements for VISTA to a sufficient level of detail for the completion of Phase A of the project. Most of the software issues are common to the visible and infrared cameras, so this document is designed to cover both of them.

The document describes all the formal software requirements necessary to ensure the visible and infrared cameras meet the specifications described in the "Applicable Documents" listed below. This includes requirements for mechanism control, detector control, data acquisition, data assessment and quality control — in short everything connected with instrument control at Cerro Paranal. Detailed observation planning, telescope control and final data reduction requirements are outside the scope. However, any assumptions about the observation planning and final data reduction that may affect the software requirements here are included.

In order to simplify the integration of VISTA into the ESO-VLT environment, the optical sensing systems (guiding, focus control and wavefront sensing) are considered part of the VISTA instrument software, so this document also contains a description of optical sensing requirements. In practice the optical sensing systems may be developed separately from the instrument software, but the instrument software will need to accommodate them.

The document begins in section 3 by looking at the boundaries of the VISTA instrument control software. Section 4 describes the VISTA instrument characteristics and section 5 describes, in an implementation independent way, the functions that the VISTA software must perform. These sections are provided as background information. At the end of the document, in section 9 on page 74, there is a description of on the mapping of the VISTA functions onto the ESO-VLT architecture and the reuse of existing ESO software.

*The most important sections of this document are the formal list of numbered instrument software requirements contained in section 7 on page 24 and optical sensing requirements contained in section 8 on page 68.*

## *1.2 Applicable Documents*

The following documents of the exact issue shown form part of the specification described in this document. Any instrument software requirements stated in the these documents are valid unless explicitly counteracted in this document. In the event of a conflict between a requirement stated in this document and the documents listed below, this document should take precedence. However, in nearly all cases this document serves to add software details to the general VISTA requirements.

Some of these documents are given a standard abbreviation (e.g. SRD, OCDD, TS) to make references to them more concise. For example, references to "[AD3]" and "TS" are equivalent. "TS 3.1" means "section 3.1 of the VISTA Technical Specification [AD3]".

[AD1] *VISTA Science Requirements*, 26 Oct 2000, VIS-SPE-VSC-00000-0001, v2.0, (SRD).

[AD2] *VISTA Operational Concept Definition*, 28 Mar 2001, VIS-SPE-VSC-00000-0002, v1.0, (OCDD).

[AD3] *VISTA Technical Specification*, 26 Sep 2001, VIS-SPE-ATC-00000-0003, draft v1.8 2609am2, (TS).

[AD4] *ESO DICB Data Interface Control Document,* 25 Nov 1997, GEN-SPE-ESO-19400-794/1.1/0

[AD5] *ESO VLT Instrument Software Specification,* 12 Apr 1995, VLT-SPE-ESO-17212-0001, v2.0

[AD6] *ESO VLT Software Programming Standards,* 10 Mar 1993, VLT-PRO-ESO-100000-0228, v1.0

## 1.3 Reference Documents

These reference documents provide further descriptive information, but are not considered part of the current document.

[RD1] *VISTA Software Architectural Design,* 5 Jun 2001, VIS-TRE-00150-0002, v0.1.

[RD2] *VISTA Computer Hardware Architectural Design,* VIS-SPE-ATC-00150-0002, v1.1.

[RD3] *VISTA Paranal Data Reduction Requirements,* 22 Feb 2001, VIS-xxx-ATC-00000-0000, v0 (draft).

[RD4] *VISTA Computer Configuration,* 29 Jan 2001, VIS-TRE-VPO-00150-0001.

[RD5] *ESO VLT Template Instrument Software User and Maintenance Manual,* 8 Apr 2001, VLT-MAN-ESO-17240-1973, v2.0.

## 1.4 Abbreviations and Acronyms

| | |
|---|---|
| ADC | Atmospheric Dispersion Compensator |
| ADU | Analogue to Digital converter Units |
| ATC | Astronomy Technology Centre |
| BOB | Broker for Observation Blocks |
| CCD | Charge Coupled Device |
| Dec | Declination |
| DR | Data Reduction |

| | |
|---|---|
| DSC | Detector Control System |
| EED | Encircled Energy Diameter |
| ESO | European Southern Observatory |
| FIQ | Final Image Quality |
| FITS | Flexible Image Transport System |
| FOV | Field Of View |
| FWHM | Full With at Half Maximum |
| H/W | Hardware |
| ICS | Instrument Control System |
| IR | Infrared |
| LCU | Local Control Unit (a VME/VxWorks system) |
| NDR | Non Destructive Read |
| NT | Normalised Throughput |
| OB | Observation Block |
| OCDD | Operational Concepts Definition Document |
| OLAS | On Line Archive System |
| OS | Operating Software |
| OT | Operational Toolkit |
| P2PP | Phase 2 Programme Preparation Tool |
| PSF | Point Spread Function |
| QC | Quality Control |
| QC0 | Quality Control level zero |
| QC1 | Quality Control level one |
| QE | Quantum Efficiency |
| RA | Right Ascension |
| RMS | Root Mean Square |
| ROI | Region of Interest |
| SAF | Science Archive Facility (in Garching) |
| SCHED | Scheduler |
| SIQ | System Image Quality |
| SM | Service Mode |
| SRD | Science Requirements Document |
| ST | System Throughput |
| S/W | Software |
| TBC | To Be Confirmed |
| TBD | To Be Decided |
| TCS | Telescope Control System |
| TO | Telescope Operator |
| TS | Technical Specification |
| UT | Universal Time[1] |
| VISTA | Visual and Infrared Survey Telescope for Astronomy |
| VLT | Very Large Telescope |
| VM | Virtual Model |
| VPPC | Vista Pipeline Processing Centre |

[1] Also "Unit Telescope" in ESO documents.

| | |
|---|---|
| VSA | VISTA Science Archive |
| WCS | World Coordinate System |
| WFS | Wavefront Sensor |

## *1.5 Definitions*

**Bad Pixel Mask:** A calibration frame mapping the location of bad pixels on each detector. The data processing pipeline uses this information to ignore data from bad pixels.

**Bias Frame:** A calibration frame taken in darkness with zero exposure time, giving a readout of the signal from each detector immediately after it has reset. The bias frame provides a zero point that can be subtracted from subsequent data frames.

**Cold Blocker:** A cold, opaque object inserted into the beam of the infrared camera to prevent external light from reaching the detector. An optical blank filter may be used for this purpose.

**Dark Frame:** A calibration frame taken in darkness with the same exposure time as the science observation it is intended to calibrate. The dark frame contains the integration of the detector dark current signal for the given exposure time, and can be subtracted from the science frame.

**Detector Control System:** The control system responsible for sequencing the detector hardware, controlling the shutter (if any) and reading out data.

**Dithering:** The process of taking several overlapping exposures at slightly different telescope positions whose differences are much smaller than the size of a detector. Dithering is used with the visible camera to fill in the small gaps between detectors and with the infrared camera to make a sky-flat.

**Dithered Map:** The image generated from a set of dithered exposures when combined together.

**Exposure:** A single exposure of the detectors resulting in a single raw data frame.

**Flat-field Frame:** A calibration frame containing an exposure of a uniform illumination, allowing the relative sensitivities of the detector pixels to be calibrated.

**Instrument Control System:** The control system responsible for controlling the instrument hardware and sensing the instrument environment. (This is the equivalent of the Components Controller for a Gemini instrument, for example).

**Instrument Operating Software (OS):** The software responsible for coordinating the telescope control system, instrument control system and detector control system.

**Instrument Software:** All the software associated with instrument control.

**Linearity Frame:** A calibration frame containing information on the rate of change of the signal for all the detector pixels as a function of exposure time.

**Observation:** A series of exposures designed to generate an image (or tile) at one location on the sky.

**Observation Request:** A complete description of an observation, or a set of observations, that need to be carried out. Regarded by the software as a complete unit. (Called an "Observation Block" in the ESO software implementation).

**Observation Planning:** The process of specifying a set of observations well in advance and submitting the specification as an observation request.

**Observation Scheduling:** The process of examining all the outstanding observation requests and converting them into an observing plan. Also the process of deciding, from current observing conditions, which observation is the best one to be executed next.

**Observing Programme:** A set of observations belonging to the same project, submitted by the same principal investigator. An Observing Programme can result in one or more Observation Requests. An Observing Programme could be the specification of an entire survey.

**Offsetting:** The process of taking several exposures at different telescope positions whose differences are larger than or comparable with the size of a detector. Offsets are used with the visible and infrared cameras to fill in the large gaps between detectors.

**Optical Sensing System:** The system responsible for monitoring the VISTA image quality. It's responsibilities divide into three functions — Guiding, Autofocus and Wavefront Sensing, which may use different sensors.

**Pointing:** A set of exposures made of a series of small dithers around a single telescope position using the same guide star(s).

**Run Number:** An incremental number used to manage the observations for a science programme or made during the night.

**Tile:** The filled image of the sky generated from a set of offset exposures when combined together. (The VISTA equivalent of the photographic plate used in older surveys). Several tiles may be combined together to make a survey.

# 2 Overview

The VISTA "instrument software requirements" are primarily derived from the “VISTA Technical Specification” [AD3] (TS), with additional information gleaned from the “VISTA Science Requirements Document” [AD1] (SRD) and “VISTA Operational Concept Definition Document” [AD2] (OCDD). The software requirements are constrained by the need for the VISTA software to be compatible with the existing ESO-VLT software [AD4], [AD5] and [AD6]. Whereas the ESO-VLT software encompases all kinds of instruments, the VISTA software will only ever control two instruments — the infrared camera and the visible camera. An overview of the VISTA telescope is given in the “VISTA Technical Specification” (TS) section 3 and an overview of the software control system in TS 5.4.

The detector arrays constrain the way observations have to be taken in order to allow data processing software to construct astrometrically and photometrically correct maps of the target sky areas. This leads to the definition of certain observing modes. Any data-taking operation has to conform to the relevant mode, and the subsequent data processing is specific to that mode. Examples of modes include obtaining a fully-sampled record of an area of sky, obtaining basic calibration data such as dark and bias frames, and obtaining a complex pattern of sky frames for internal astrometric calibration of the detectors.

Operationally, the system is intended as a survey telescope designed to carry out observations efficiently and with minimal intervention from the operator who will be absent from the VISTA building and who will have other duties. This leads inevitably to a system in which the observations are pre-planned in detail, and the observation request is stored in a machine-readable form such that it can selected by the VISTA real-time system (possibly with operator assistance) and executed.

The obtained datasets have to be archived and exported to a data processing system which produces reconstructed calibrated maps of the sky, and also catalogues of the properties (photometry, position, morphology) of astronomical sources found within the maps. The data processing system is not part of the current project, but obviously some account has to be taken of its requirements here to ensure that the final output has its intended scientific value.

Maximising the overall efficiency of the system also means that system failures have to be detected and reported promptly. This extends to checking the quality of the data being obtained and to monitoring the state of both cameras.

In order to relate this derivation of requirements to implementation issues, sections are included indicating how the system might map onto the ESO-VLT software architecture, and discussing the issue of FITS header items in the archived data.

# 3 System Context

## *3.1 Boundaries of the system*

In order to derive the requirements of a system it is necessary to define its boundaries and define what things in the outside world it interfaces to. In the case of VISTA the general system context for the instrument software looks like this:

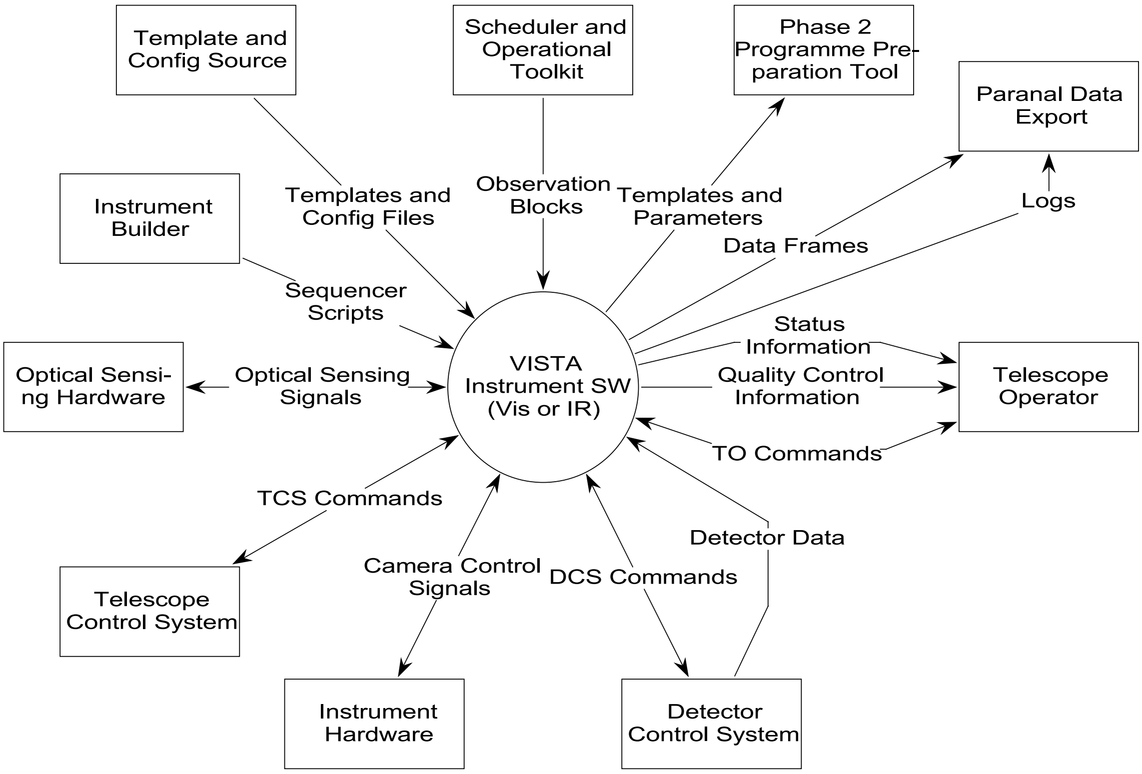


**Figure 1 General context of the VISTA instrument software (visible and infrared)**

The instrument builder supplies information about each instrument. An observation planning system generates (with the aid of a system description) observation requests which the instrument software converts into commands which are sent to the Optical Sensing Hardware (for wavefront sensing and guiding), the Telescope Control System (for dithering and other mapping), the Instrument Hardware and the Detector Control System. The detector generates data which is used to generate quality control information and is exported off site for final data reduction. Logs are generated to record significant events and provide a record of each night's observing. The whole process is monitored and controlled by the Telescope Operator.

In practice, the VISTA software architecture is constrained by the ESO-VLT software architecture [AD5], as described in section 9 on page 74. (See also TS 5.4, 5.5).

## *3.2 System Interfaces*

The following system interfaces need to be specified:

- VISTA instrument software to Instrument Builder (information provided by the instrument builder);
- VISTA instrument software to Observation Planning System (system description and observation requests);
- VISTA instrument software to Optical Sensing Hardware (Optical sensing commands and responses);
- VISTA instrument software to Telescope Control System (TCS commands and responses);
- VISTA instrument software to Instrument Hardware (Camera Control Signals);
- VISTA instrument software to Detector Control System (DCS commands and responses);
- VISTA instrument software to Telescope Operator (TO commands, status information and quality control information);
- VISTA instrument software to Off-site Data Export (data headers and data, information logged).

# 4 VISTA Camera Characteristics

The characteristics of both the infrared and the visible cameras (summarised in TS 5.2 and 5.3) dictate certain features of how the system has to be driven. These characteristics include the photometric behaviour of the detector arrays (flat-field, bias, dark, linearity), the physical layout of the mosaic of detectors in the focal plane, and the requirements placed on the mechanisms that need to be controlled. The following are salient points extracted from the VISTA requirements documents.

## *4.1 Visible Camera Mechanisms*

The visible camera (see TS 3.4.1, 4.8.2, 5.2) has the following mechanisms:

- An atmospheric dispersion compensator (controlled by the instrument controller but monitored by the telescope control system to enable pointing corrections). Tracking the ADC during an exposure is not essential. (TS 5.2.2).
- A filter cassette capable of containing at least 10 filters, which will include colour filters covering the 7 visible bands listed in TS 4.7 and 5.2.3 plus a neutral density filter and an opaque blank filter. The filter positioning should be repeatable to a high accuracy and each filter should have a unique machine-readable identifier (TS 5.2.4). Automatic focus adjustment may be necessary on changing a filter.
- A shutter (controlled by the detector controller), accurate enough to reconstruct the absolute time of mid exposure to within 0.1 seconds (TS 5.2.5).
- A collection of visible guiders and wavefront sensors controlled by the optical sensing system (TS 5.2.8).

## 4.2 Visible Camera Detector

The baseline assumption is that the visible camera detector will be a 5x10 mosaic of 50 CCDs, each 2048-by-4608 pixels (TS 5.2.7). The individual pixels are 13.5microns in size, corresponding to 0.232arcsec per pixel. The arrays can be close-butted on three sides in order to make mosaics with contained gaps about 1mm in width.

The fourth side requires more space. The baseline proposal is to make the camera using three close-butted mosaics with larger gaps between them, as shown in Figure 2. The exact size of the larger gap (15-25mm) depends upon the detector packaging and the geometry of the filters.

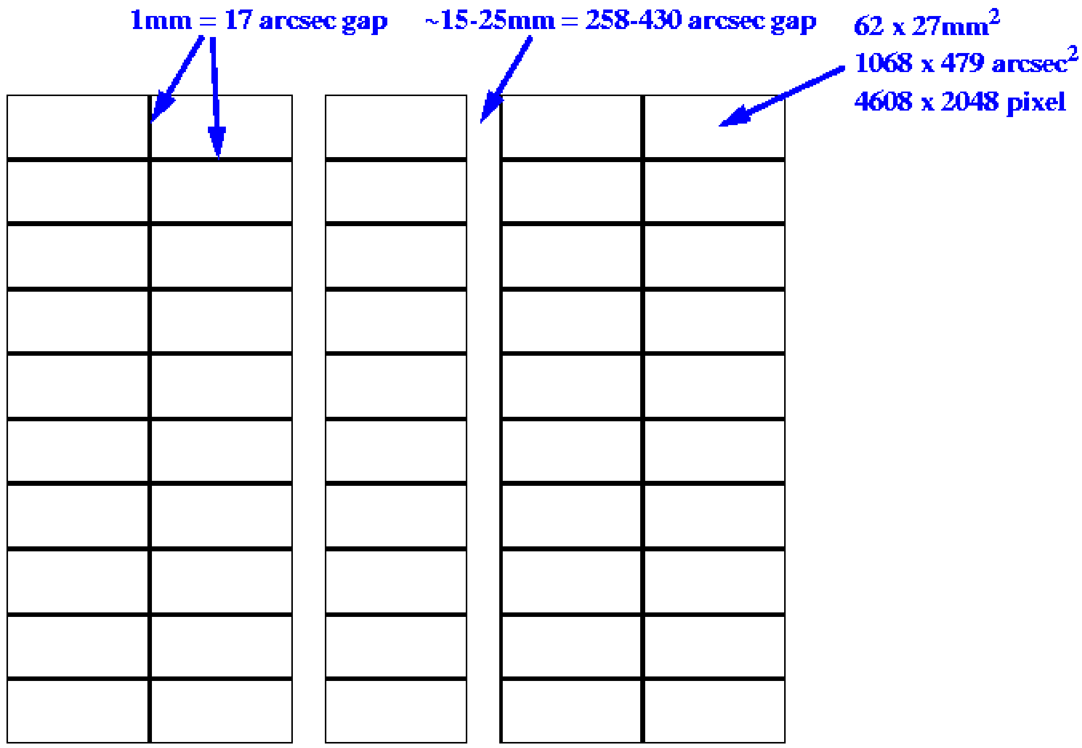


**Figure 2 Visible Array Mosaic**

## 4.3 Infrared Camera Mechanisms

The infrared camera (see TS 3.4.2, 4.8.3, 5.3) has the following mechanisms:

- A filter wheel capable of containing up to 8 filters, covering the 3 nominal IR pass bands listed in TS 4.7 and 5.3.2. One of the filters will be an optical blank. Another may be in the optional $Z^{IR}$ pass band (TS 5.3.3).
- A collection of visible wavelength guiders and wavefront sensors controlled by the optical sensing system (TS 5.3.7).

## *4.4 Infrared Camera Detector*

The baseline conceptual design of the infrared camera focal plane unit consists an array of 16 infrared detectors each 2048 pixels square, in a 4-by-4 pattern with gaps of 90% of a detector width between them (TS 5.3.6), as shown in Figure 3.

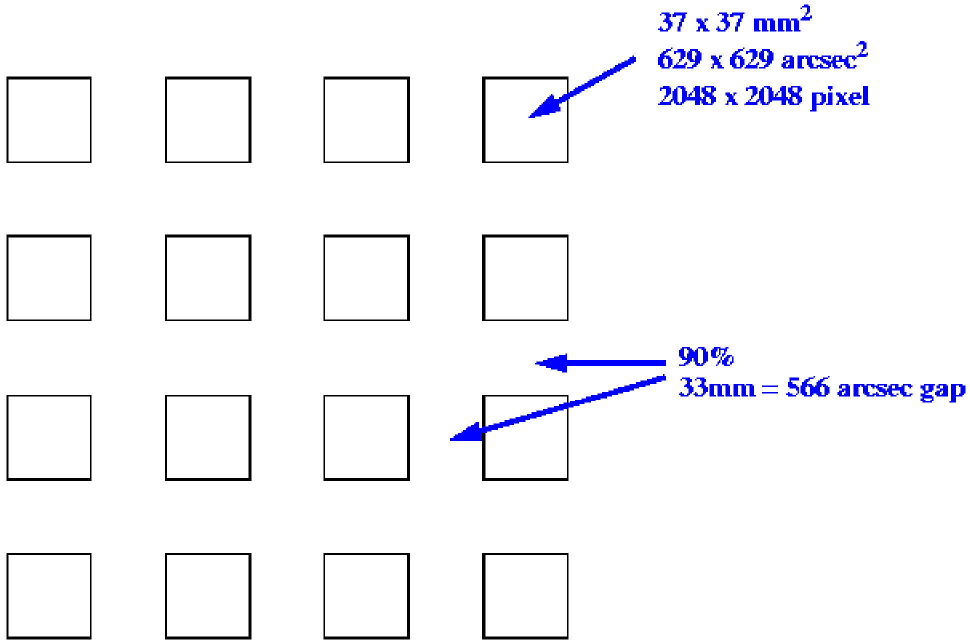


**Figure 3 Infrared Array Mosaic**

## *4.5 Dither and Offset Patterns*

When a single observation is made with either the visible or infrared detectors significant areas of sky will fall in the gaps between the detectors and not be recorded. To make an unbroken image of the sky, several observations made at slightly different offsets the sky need to be combined together. This collection of observations is known as a dither pattern when the image shift is small and an offset pattern when the shift is large.

Besides filling in the gaps between sensors, the infrared camera can also use a dither pattern to generate a sky background flat field from science observations (for example by generating a median frame). Both cameras can use dither patterns to reduce the effect of bad pixels and bad columns on the detectors.

Both cameras will require dither patterns operating on at least two different distance scales. The reasons, which differ for the two cameras, are described below.

### 4.5.1 Visible Camera Dither Patterns

In order to remove the 1mm gaps between the visible detectors, dither patterns must consist of at least three positions on a diagonal line. Two dithers can be used if it is acceptable to have 1mm square gaps in the data. The three position form of dither pattern results in a 3:1

ratio in integration times between the best and worst observed sky areas, even ignoring the possibility of bad pixels. This effect is shown in Figure 4, where the darker areas have the greater exposure time.

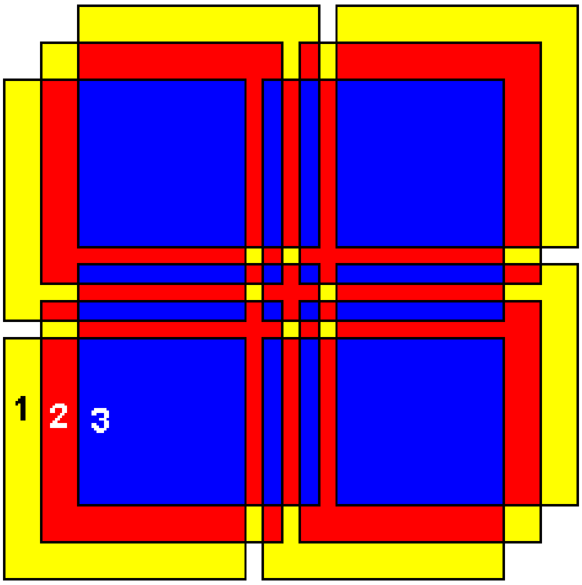


**Figure 4 Overlapping of dithering patterns showing ratio of integration times**

The dither pattern needs to be arranged to minimise the effect of these different exposure times, and the data reduction software needs to take these exposure differences into account.

Although it is possible to cover both the large and small gaps on the visible array with a single dither and offset pattern (with small dithers in Y and large offsets in X), such a pattern leads to greater field distortions and greater PSF variations because of the large number of places where objects are recorded at the edges of different CCD chips, and because of the fact that the pixel scale can change slightly from one edge of a chip to another. It is preferable to cover the 1mm gaps separately with a series of small scale dither moves. This also increases the probability that the same guide star can be used for all the dither positions. A large scale offset can then be used to cover the large (15-25mm) gaps and even out the exposure differences across the whole field (see the OCDD [AD2] section 5.5). If the 1mm gaps between the chips don't matter, the large gaps between the chips can also be filled in with a simple offset pattern made of two exposures offset by 2 chip widths.

The software should include some standard dither and offset patterns, and the design of these patterns has to include a cross-checking on the effect of field distortion [AD1].

### 4.5.2 Infrared Camera Dither Patterns

The 90% gaps in the infrared camera can be covered by means of a large scale offset pattern made of four observations offset by (0,0), (0,0.95), (0.95) and (0.95,0.95) chip widths. A more complex series of offsets would be required to fill in a 45% gap. In addition, infrared observations will need a small scale dither pattern to enable the construction of median sky flats (see the OCDD [AD2] section 5.5). The most common of these small dither patterns will be a series of nine observations in a 3x3 grid.

## *4.6 Data Acquisition Modes*

"Data Acquisition Modes" are a convenient packaging of the primitive capabilities of the system into standard methods of acquiring data. Many of them arise from commonly-repeated calibration activities, which are described in detail in OCDD [AD2] section 6.

### 4.6.1 Dithered Map

Most observations will involve both small and large scale dither moves. The observation request has to contain a specification of the dither pattern. The pattern has to allow moves to fractional pixel precision to allow microstepping. At a high level the pattern of offsets must be expressible in either arcsec or pixel numbers in a coordinate system defined relative to the array geometry. It is possible that wavefront sensing measurements may have to be interleaved inside dithered observations.

### 4.6.2 Determine detector layout

The focal plane positions and orientations of all the detectors have to be known for astrometric accuracy across the field of view (the required accuracy is described in [AD1] section 4.5.1). The resulting parameters have to be stored as part of any observation in the FITS headers, probably by the Detector Controller. However, these values have to be determined in the first place and reconfirmed at intervals subsequently (a method is outlined in [AD2] sections 6.1.5 and 6.2.11).

### 4.6.3 Determine bad-pixel mask

In order to generate reliable data quality information there needs to be a map of the bad pixels on each detector (so these pixels are excluded from the data quality calculations). The bad pixel map can also be used to exclude bad pixels from the scaling of on-line data displays. However, monitoring the number and position of bad pixels is in itself a data quality operation. It is expected that a bad pixel mask will be defined initially from calibration observations and that map be refined regularly as part of the quality control process. Determining the bad pixel map may involve interpreting the results from a combination of bias/dark/flat-field frames.

### 4.6.4 Determine detector bias

This involves obtaining an exposure with "zero" integration time with the dark shutter closed (visible). Bias frames are not needed for infrared observations. A “master bias” can be created from several bias exposures to reduce the read noise and/or remove cosmic ray events ([AD2] section 6.1.1).

### 4.6.5 Determine detector dark signal

This involves obtaining an exposure with the dark shutter closed (visible) or with the cold blocking filter selected (infrared) ([AD2] sections 6.1.2 and 6.2.2). A dark exposure must have the same exposure time as the science observation it is intended to calibrate (unless the detectors can be shown to have a perfectly linear dark current which may be scaled with exposure time).

### 4.6.6 Determine detector flat-field from dome illumination

This involves obtaining a high signal-to-noise image of an artificial uniform illuminated field of view ([AD2] section 6.1.3).

### 4.6.7 Determine detector flat-field from twilight

This involves obtaining a series of exposures of the twilight sky with angular offsets between them ([AD2] section 6.1.4).

### 4.6.8 Determine detector flat-field from night sky

A sky flat-field can be created by taking the median of infrared observations taken with a small scale dithering pattern ([AD2] section 6.2.4).

### 4.6.9 Determine detector linearity correction

This involves performing a series of flat-field exposures of differing exposure times, or using pre-flash LEDs inside the camera ([AD2] sections 6.1.10 and 6.2.7).

### 4.6.10 Photometric calibration

This involves observing fields containing standard stars at regular intervals through the night. Bright standards may need a short exposure. The calibration may also involve locating any standard stars included in the regular observations and cross referencing information from standard star catalogues ([AD2] sections 6.1.6 and 6.2.12).

# 5 VISTA Software Functions

These are the functions that the VISTA software needs to perform. Some of these functions are outside the scope of instrument control, but are described here for completeness. A comparison of the VISTA software functions and ESO-VLT software functions is given in section 9 on page 74.

## *5.1 Optical Sensing*

VISTA's instrument systems, rather than the telescope control system, will control subsystems that generate guiding corrections, focus corrections and higher order wavefront corrections. Although these subsystems may be developed separately from the instrument software, the instrument software will need to accommodate them. The requirements are listed in section 8 on page 68

## *5.2 Planning Observations*

It must be possible to prepare an observing programme well in advance of observing. A software utility has to exist to assist in the production of requests. Given the survey nature of VISTA, the software utility must make it easy to generate requests for sets of observations, such as a whole series of survey fields with observations through a list of filters, but the same observing modes and other details.

An “Observing Programme” is defined as all the observations needed to carry out a particular scientific investigation, or complete a particular survey. Examples of a VISTA observing programme might be:

- Observe the whole sky south of Declination –30˚ with the visible camera and the r´ filter.
- Observe a 10˚ x 10˚ area of sky centred on the South Galactic Pole with the IR camera and the H filter.
- Observe a certain area of the sky with a specified list of filters.

By comparison, an “Observation” is defined as the collection of exposures, with one instrument and one filter, needed to make one fully sampled dither pattern on the sky.

### 5.2.1 Observing Programme

An observing programme definition has to contain the following information.

**Programme Identification**

This should contain items such as the name of the Principal Investigator, a programme title, and an assigned priority for the whole observing programme.

**One or More Observation Requests**

Each observing programme will contain references to one or more observation requests, which are scheduled as individual observations.

### 5.2.2 Observation Request

Each observation request has to contain the following categories of information.

**Programme Reference**

The title of the observing programme to which this observation belongs, the programme priority and the name of the principal investigator.

**Target Details**

Name of field, position of centre of field, list of reference objects within field.

**Telescope Tracking**

Sidereal/non-sidereal rate specification, guide star characteristics (certain observing modes may require a list of guide stars), beam rotator angle, atmospheric dispersion compensator setup.

**Observing mode and its parameters**

Choice of mode, arguments specific to mode (e.g. scale for scalable dither patterns, integration time, filter(s)).

**Scheduling Constraints**

Acceptable state of the moon, atmospheric seeing, transparency and airmass and priority within the observing programme. Any absolute or relative time constraints.

**Data Processing Options**

These should provide information needed by the local data processing system and the final data processing system.

## 5.3 *Scheduling Observations*

The next observation to be made by the telescope has to be selected from the existing set of observation requests.
The selection has to be made on the basis of:

- Requested instrument matching the instrument on the telescope and the requested filters etc. actually being installed in the instrument
- Requested pointing centre being available and current Sidereal Time meeting Hour Angle and Zenith Angle constraints
- Current absolute time within requested constraints (if any)
- The current airmass of the pointing centre within requested constraints.
- The current phase of the Moon and angular distance of the pointing centre from the Moon within requested constraints
- Actual sky conditions (seeing, humidity, cloud cover etc.) within requested constraints
- Priority

The selection is likely to be made by the combination of a database search tool and the operator.

The selection will normally produce a list of observations to be carried out as a group (e.g. observations with different filters). These should be fed to the system which executes observations one at a time. When an observation is completed successfully, this should be recorded in the scheduling system to prevent it being re-selected. The observation request is only finally marked as satisfied once final data processing has been applied to it. In the event of any problem, the request is restored to enable it to be rescheduled.

If an error is reported by the system which executes observations, then observation scheduling stops pending action by the telescope operator.

If a quality control metric does not meet expectations, the telescope operator can reschedule an observation at a later time (usually the following night).

## 5.4 Executing Observations

An observation is executed when a request is obtained from the observation scheduling system. The request is interpreted, and the operations demanded by the observing mode and its parameters carried out. Header information is collected and appended to the obtained data. The scheduling system is informed of the success or failure of the observation. If an error is detected during an observation, then that observation is terminated as quickly as possible.

During execution, there must be a display providing the information about the progress of the observation, as well as status displays showing the overall health of the system. At the end of an observation some simple confirmation of the quality of the data should be displayed (for example, a flat-fielded image display of the image obtained by one of the detectors, together with important quality control metrics).

## 5.5 Generation of Data Products

The Observation Execution system has to export the obtained pixel data along with header items such as the original observation request, the true exposure duration and its timing, details about the actual state of the telescope and the instrument and weather information. The geometry of the arrays also has to be recorded for astrometric accuracy (specified in [AD1] section 4.5.1). All the necessary information to process the data needs to be contained in the data header.

## 5.6 Generation of End-of-Night Reports

A data processing system local to the telescope will carry out checks on the quality of data obtained during the night, and at the end of the night (before local mid-day) will produce summary reports sufficient to allow detection of any obvious errors in the system. Parameters to be produced include sky background level and noise from each detector, and photometric zero point estimates. Guide star position offsets (i.e. pointing errors) should also be summarised, along with monitored instrument environment values (cryostat temperature trends) and weather station measurements.

The large number of detectors (50 for the visible camera) means that some kind of graphical display is necessary even for simple statistics of the detector behaviour. The aim should be that a trained operator should only require a few minutes to confirm that the system behaved normally, or to spot gross inconsistencies (e.g. a large change in the apparent sensitivity of one of the detectors).

## *5.7 Quality Control*

Quality control in VISTA involves detecting and reporting in real time certain problems that may have affected an observation, recording a log of a night's observing and analysing the subsequent data to determine quality control metrics. These metrics allow the telescope operator to decide whether an observation needs to be repeated.

### 5.7.1 Detecting Problems

The software systems can make deductions about the general health of VISTA during observing, and also can evaluate the quality of the data obtained at various stages during data processing. The following table provides a list of relevant problems and their symptoms. The scheme follows the path of information flow, from astronomical objects through to data processing.

| Problem | Symptom |
|---|---|
| Guide star is variable | Autoguider sees wrong magnitude |
| Guide star is double | Autoguider sees badly structured image |
| Poor atmospheric transmission | Autoguider sees wrong magnitude |
| Poor seeing | Autoguider sees broad image |
| Telescope pointing problem | Autoguider fails to find guide star |
| Telescope tracking problem | Autoguider demands many corrections |
| Telescope out of focus | Autofocus detects the condition |
| Autofocus failure | Autoguider sees broad image |
| Field rotator failure | Autoguider fails to find guide star |
| Autoguider failure | Camera sees trailed images |
| Atm. disp. compensator failure | Camera sees slightly degraded images |
| Misting of optics | Camera sees wrong photometric zero points |
| Filter choice failure | Filter readout wrong |
| Filter readout failure | Camera sees bad photometric zero points |
| Misting of detectors | Camera sees bad photometric zero points |
| Electrical failure of detectors | Wrong zero points, wrong noise level |
| Cryogenic failure | Temperature monitor detects the condition |
| Temperature monitor failure | Camera sees excess dark background |
| Failure in data/header recording | Failure to locate standard stars |
| Wrong data processing parameters | Wrong catalogue limiting magnitude |

Because VISTA is to be operated as automatically as possible, it is very important to maximise the number of problem areas which can be detected as automatically and as rapidly as feasible. Taking an unlikely problem as an example, erratic behaviour of the filter change mechanism should not have to be deduced from strange field effects in the photometry calculated during the final data analysis, leading to a one week turnaround in tracing failures. Instead, the system should be able to confirm that the actual filter position matches the demand and to report a real-time error in the event of failure.

The table reveals that the autoguider can play a big role in detecting the commonest problems. If the autoguider is assumed to be a CCD array with a suitable colour filter matching a standard photometric wavelength band, then the basic operation of the CCD software could be sky subtraction followed by moments analysis of the stellar image. This would give the position of the image, which is the guiding information, plus the brightness and extent of the image. If the guide star was required to be chosen such that it had known magnitude, then an approximate photometric zero point calculation could be made. These parameters could provide the various diagnostics indicated in the table.

## *5.8 Final Data Processing*

This is not part of the current project, but certain assumptions have to be made about it.

The final data processing system does not have access to the observing system. This means that it cannot request extra bits of information from the software running at the telescope - indeed, it is assumed that it might be up to a week between observations being taken and them being given to the final data processing system. This means that the data delivered have to be self-sufficient. All necessary header information and calibration frames have to be included in the Data Products exported from the observatory to the final data processing system.

It is expected that there will be some feedback mechanism from the final data processing system to the observation scheduling system, so that observations are not considered finally complete until their data processing has ended successfully.

Dark, bias, flat-field and linearity frames have to be processed and their results stored and identified such that they can be applied to science frames.

Dithered datasets have to be combined taking account of bad-pixel masks and the dithered offsets. The combination has to be performed after registering images in overlapped areas ([AD2] OCDD 5.5.1).

Assuming satisfactory basic operations (flat-fielding etc) have been carried out, then some of the data processing alternatives might be as follows, given that dithering means there is non-uniform coverage of the field of view (see [AD1] SRD 4.6.4).

### 5.8.1 Simple Combined Image and Catalogue Production

This is intended to achieve the simplest reconstruction of a dithered map and to extract a catalogue of astronomical sources from it.

An initial image segmentation and object parameter calculation occurs on a per-detector basis. The transformation between different steps in the dither pattern is then determined from pairing data for objects which are found common to the different exposures. The pixel data for the full dithered set are then re-sampled onto the final co-ordinate system. Image segmentation and object parameter calculation are then performed for the combined image.

This gives the initial catalogue. Subsequent processing on the catalogue adds star-galaxy separation tags and determines and applies astrometric and photometric calibrations.

### 5.8.2 Uniform Contiguous Sky Coverage

This is intended for statistical survey investigations where both uniform magnitude limit and continuous angular coverage is required (e.g. some kind of study of clustering). The procedure starts as above, but the combined resampled image is generated to match the integration time of the least-observed sky areas in the dithered set (i.e. excess multiple observations of sky pixels are discarded). This gives an image with uniform signal-to-noise (subject to detector uniformity). Segmentation and parameter calculation then delivers a catalogue with the required uniformity, at the cost of discarding a lot of recorded photons.

### 5.8.3 Uniform Deepest Sky Coverage

This is intended for statistical survey investigations where uniform magnitude limit is required, but angular structure is not relevant (e.g. source counts). The procedure starts as for the simple case, but the combined resampled image is generated to match the integration time of the most-observed sky areas in the dithered set (i.e. observations of sky pixels which fell in array gaps at other steps in the pattern are discarded). This gives an image with extensive missing strips, but uniform maximum signal-to-noise ratio in the observed regions.

### 5.8.4 Non-Uniform Statistical Sky Coverage

It is possible to combine exposures together and generate a meaningful result without discarding any data. To do this the data reduction software needs to determine both the mean and standard deviation of the illumination across the field. Such a mode might be used for observations of an extended object (such as a comet) where gathering information about the intensity is more important that generating a catalogue of objects.

# 6 Software Functions Excluded

The following software functions have been excluded because they are of little benefit to a survey telescope such as VISTA and do not fit easily into the ESO-VLT model. They are listed here to show they have not been overlooked:

- The VISTA science instruments do not need the ability to pause and continue exposures while they are in progress. If anything happens during an exposure that compromises its data quality (e.g. deterioration in sky conditions) the entire exposure will be repeated. This simplifies the observing system.
- The VISTA science detector controllers do not need the ability to read out a subset of their pixels into regions of interest. Such an observing mode would not be making the most efficient use of VISTA.
- VISTA will not have a chopping secondary mirror, so the infrared camera does not need to ability to synchronise its detector controller with the M2 controller.

- The VISTA telescope will be used for imaging only. The instrument software does therefore not need to consider the effect of introducing a dispersing element into the system. This means that:
  - When World Coordinate System information is derived, it can safely be assumed that all data have been acquired in imaging mode;
  - The effective wavelength of any observation made by a camera will be determined by its filter.

# 7 VISTA Instrument Software Requirements

There are a number of explicit requirements placed on the VISTA Instrument Software, and these are listed here with their sources. The main sources are as coded follows:

- **TS** — *"Technical Specification"*, [AD3].
- **SRD** — *"Science Requirements Document"*, [AD1].
- **OCDD** — *"Operational Concepts Definition Document"*, [AD2].

Requirements labelled "**[NEW]**" are new requirements that don't have a source within any of the above documents.

## *7.1 Observation Planning and Scheduling Requirements*

**ISR010010** **Observation planning software shall allow an observing programme to be prepared well in advance of observing.**

**Need:** Requirement **Source: TS 3.7.2, 6.1.4**
**See also: SRD 7.3**

**Description:** A software facility has to exist to allow an observing programme to be specified and planned in advance. *However, this is not considered a requirement on the VISTA Project Office. Development of such a tool should be considered by ESO, e.g. for use also on the VST.*

**ISR010020** **Observation scheduling software shall allow an observing programme to be carried out with minimal intervention from the telescope operator.**

**Need:** Requirement **Source: TS 3.7.2, 6.1.4**
**See also: SRD 7.3**

**Description:** An intelligent software facility has to exist to schedule observation requests based on the scheduling constraints contained within them. The software should be able to run with minimal intervention from the telescope operator, but facilities must exist to give the telescope operator the final say over which observations are executed and when.

**How to test:** To be tested by reviewing the software design.

**ISR010030 An observation request shall completely specify an observation.**

**Need:** Requirement **Source: TS 3.7.2, 6.1.4**
**See also: OCDD 3.6**

**Description:** In order to support queue-based observing, the instrument software must be designed so that an observation request completely specifies an observation (although the guide, focus and WFS stars can be overridden at the time of the observation [ISR010040 below]).

There should only be minimal intervention by the telescope operator (with the exception of guide, focus and WFS star choice). To allow this semi-automated operation, an observation request should contain at least the following information (OCDD 3.6):

- Programme identification
  - Name of principal investigator
  - Unique science programme identifier
  - Programme title string (defined by scientist)
  - Programme priority (assigned by committee)
- Observation identification
  - Unique observation identifier
  - Observation priority (defined by scientist)
  - Nightly priority (used to define the priority of this observation within a nightly schedule)
  - Special priority (used for special purposes)
- Target details
  - Name of field (standard name for the field)
  - Description of field (defined by scientist)
  - Celestial coordinates of the field centre
  - Proper motion of target (SRD 4.5.3/4)
  - Epoch of target coordinates (SRD 4.5.3/4)
  - Equinox of target coordinates
- Suggested guide star details (one or more guide stars) [see ISR100040 on page 68]
  - Name of each guide star
  - Celestial coordinates of each guide star
  - Proper motion of each guide star (SRD 4.5.3/4)
  - Epoch of each guide star coordinates (SRD 4.5.3/4)
  - Equinox of guide star coordinates
- Suggested focus star details (one or more focus stars, can be the same as the guide stars) [see ISR100040 on page 68]
  - Name of each focus star
  - Celestial coordinates of each focus star
  - Proper motion of each focus star (SRD 4.5.3/4)
  - Epoch of each focus star coordinates (SRD 4.5.3/4)
  - Equinox of focus star coordinates

- Suggested WFS star details (one or more WFS stars)
  - Name of each WFS star
  - Celestial coordinates of each WFS star
  - Proper motion of each WFS star (SRD 4.5.3/4)
  - Epoch of each WFS star coordinates (SRD 4.5.3/4)
  - Equinox of WFS star coordinates
- Telescope Tracking requirements
  - A non-sidereal tracking rate in arcsec/minute (if required)
  - Absolute UT to which the non-sidereal tracking rate applies.
  - Position angle of camera Y axis defined on the sky in degrees (SRD 4.5.2/3)
  - Specification of the dither pattern. The name of a standard pattern, or the number and spacing of dither offsets (specified either in arcsec of Ra,Dec on the sky arcsec of Alt,Az or in camera pixels in x,y)
- Instrument Requirements
  - Name of instrument to be used (visible camera or infrared camera)
  - Name of filter required
  - Required shutter behaviour during exposure (open, closed or a pattern of open/close operations[2]) (visible camera only)
  - Whether cold blocking filter is deployed (infrared camera only)
  - Exposure time required for each dither position (as a function of observing conditions — e.g. separate exposure times required for the best, average and worst acceptable atmospheric conditions).
  - Detector on-chip binning factors (1x1 or 2x2) (visible camera only)
  - Detector readout speed (visible camera only)
  - IR detector readout behaviour (TBD — e.g. could be number of reads in an NDR sequence) (IR camera only) (OCDD A2.6)
  - ADC behaviour (nulled, set to cancel at mid exposure or tracking) (visible camera only)
- Scheduling constraints
  - Range of acceptable phases of the moon
  - Range of acceptable sky brightness values (visible observation only)
  - Range of acceptable atmospheric seeing values in arcsec
  - Range of acceptable airmass values
  - Range of acceptable atmospheric transparency values
  - Required range of absolute date/times for the observation[3] (if any)
  - A means of linking observations from the same observing programme into a particular order with particular timing constraints between each one (if required). For example:
    - ID of the previous observation in the linked sequence (if any)
    - ID of the next observation in the linked sequence (if any)

[2] Multiple shutter open/close operations within an exposure might be used to identify the direction of travel of a trailed asteroid, for example.
[3] This parameter can be used to specify a timed series of observations than must happen on particular nights.

  - Required relative time lapse (within a night) between this observation and the previous observation in the linked sequence[4] (if any)
- Calibration requirements, such as
  - Whether this observation requires a bias frame, and the maximum acceptable time lapse (in hours) between the bias and this observation.
  - Whether this observation requires a dark frame, and the maximum acceptable time lapse (in hours) between the dark and this observation.
  - Whether this observation requires a flat-field frame, and the maximum acceptable time lapse (in hours) between the flat-field and this observation.
  - Whether this observation requires a sky-flat frame, and the maximum acceptable time lapse (in hours) between the sky-flat and this observation.
  - Whether this observation requires a twilight-flat frame, and the maximum acceptable time lapse (in hours) between the twilight-flat and this observation.
  - Whether this observation requires a separate photometric standard observation, and the maximum acceptable time lapse (in hours) between the photometric standard and this observation.
- Data processing options, such as
  - Number of exposures (making up the total specified exposure time) to coadd before storage.
  - Whether this observation is a bias, dark, flat-field, sky-flat, twilight-flat, photometric calibration or science observation etc.

NOTE: The exact definition of an Observation Request needs to be specified in an *Observation Planning Software to VISTA Instrument Software* Interface Control Document (see ISR070010 on page 67) and may evolve, subject to change control, during the software design.

**How to test:** To be tested by reviewing the software design.

**ISR010040 The observation scheduling software shall allow guide, focus and WFS stars to be chosen on the fly**

**Need:** Requirement **Source: TS 4.13.2 6.1.4**
**See also: OCDD 5.2**

**Description:** An observation request can contain a description of recommended guide, focus and WFS stars. The software must allow the telescope operator to override this choice and select different stars according

[4] If this parameter is set to zero it means the observation should follow on as soon as possible after the previous one, which can be used to ensure a set of infrared observations of the same field with different offsets are carried out together.

to the observing conditions. There should be a utility to search for guide stars in an on-line catalogue. [See ISR100060 and ISR100070 on page 69 and ISR110010 and ISR110020 on page 71].

**How to test:** To be tested by reviewing the software design and trying out scenarios in which the operator overrides the choice of guide star.

**ISR010050 The observation scheduling software shall check observation requests before submitting them**

**Need:** Requirement **Source: TS 6.1.4, 7.2.1**
**See also: SRD 6, OCDD 4.1.2/6, 4.2.2/6**

**Description:** The observation scheduling software must check, using all the information available to it, that an observation request is self consistent, feasible and capable of being executed, before submitting it. The scheduling software must also check that the requested instrument is installed on the telescope and before passing the request on to the instrument control software. This requirement arises from the need to maximise observing efficiency and survey speed.

**How to test:** To be tested by reviewing the software design and by testing the system's response to faulty observation requests.

**ISR010060 The observation scheduling software shall schedule calibration observations as specified in the observation request or when demanded by the telescope operator**

**Need:** Requirement **Source: TS 3.7.1, 6.1.3**
**See also: OCDD 6**

**Description:** The observation request contains information about the calibration requirements of each observation. The observation scheduling software must ensure that the following calibrations are made when required (see section 7.4.3 on page 51):

- Bias Frames (OCDD 6.1.1, 6.2.1)
- Dark Frames (OCDD 6.1.2, 6.2.2)
- Dome flats (OCDD 6.1.3, 6.2.3)
- Twilight flats (OCDD 6.1.4, 6.2.4) (TS 08.080)
- Astrometric standards (OCDD 6.1.5, 6.2.11)
- Photometric standard observations (OCDD 6.1.6, 6.2.12)

**How to test:** To be tested by reviewing the software design and by testing the response of the system when observation requests that need a calibration are submitted.

**ISR010070 There shall be a check at the beginning of each night that all systems are ready for science observations**

**Need:** Requirement **Source: TS 7.2, 7.3.4**
**See also: OCDD 4.1.2/6, 4.2.2/6**

**Description:** The observation scheduling software (or whichever system manages night time operations) must check at the beginning of each night that all the systems are ready to begin the night's observations. Such checks will include:

- Whether the telescope and instrument systems are working normally (e.g. by invoking a simple self-test and examining the status).
- Whether the necessary calibration frames have been made successfully.
- Whether the instrument image quality and throughput is as expected (which can be deduced from the calibration observations).
- Whether there is sufficient free storage space to contain the night's expected data volume.

This requirement implies that the telescope and instrument systems must have a simple self-test facility [ISR050080 on page 60].

**How to test:** To be tested by reviewing the software design.

**ISR010080 It shall be possible to specify observations based on a standard set of dither and offset patterns**

**Need:** Requirement **Source: TS 6, 4.8**
**See also: SRD 6.3/2, OCDD 5.5.1, 5.5.2**

**Description:** Observation planning will be made easier if the software allowed the observer to select from a number of standard dither patterns. These patterns have to include cross-checking the effect of field distortion. Examples of standard dither/offset patterns might include:

- Visible Camera Dither/Offset Patterns
  - 2 observations with a large X offset to fill in the large gap and leave the 1mm gaps.
  - 3 observations with large X offsets and small Y dithers, to fill all the large and small gaps but leave field distortions.
  - 4 observations with a pattern of large and small scale offsets which leaves 1mm square holes.
  - 6 observations with a pattern of large and small scale moves which leaves no 1mm square holes.
- Infrared Camera Dither/Offset Patterns
  - 4 observations with offsets sufficient to fill in the detector gaps.

- 9 observations with a small scale dither pattern used for generating a sky flat.

**How to test:** To be tested by reviewing the software design.

**ISR010090 It shall be possible to extend the list of standard dither and offset patterns**

**Need:** Requirement **Source: TS 6, 4.8**
**See also: OCDD 5.5.1, 5.5.2**

**Description:** To cater for patterns of observations that are not covered by the standard dither and offset patterns, it must be possible to extend that list and add other patterns specified either as a series of steps on the sky in arcseconds or as a series of steps in detector pixel coordinates. Such patterns must be acceptable to the VISTA Science Processing Data Centre (OCDD 3.6/6) before they are added to the list.

**How to test:** To be tested by reviewing the software design.

**ISR010100 Dither patterns shall support offsets of fractions of a pixel**

**Need:** Requirement **Source: TS 4.8**
**See also: OCDD 5.5.1, 5.5.2**

**Description:** Dither patterns using offsets of fractions of a pixel must be allowed, to enable microstepping. This requirement implies that the data reduction system (outside the scope of this document) also has the ability to resample and combine exposures shifted by fractions of a pixel.

**How to test:** To be tested by reviewing the software design and by specifying a dither pattern offset by a non-integer multiple of the pixel size.

**ISR010110 There shall be a real time status display**

**Need:** Requirement **Source: TS 5.5.4, 7.3.4**
**See also: SRD 7**

**Description:** There needs to be a real time display providing at least the following information to the telescope operator:
- A listing of the telescope and instrument parameters (e.g. object name, requested RA,Dec, dither offset, filter and exposure time etc.) extracted from the currently executing observation request (as listed in ISR010030 above)
- Whether an observation is in progress and its status (e.g. count down of exposure time left)

- The overall health of the system (whether the telescope and instrument systems are fully operational)
- Any system faults
- Instrument status information such as:
  - current position of mechanisms
  - whether mechanisms are "in-position"
  - whether mechanisms are moving
  - cryostat temperature
  - whether any instrument components, such as neutral density filters, are degrading the signal
- The sky conditions reported by the seeing monitor
- Environmental conditions (temperature, humidity, wind speed, etc.)
- The status of the autoguider [as listed in ISR100120 on page 71]
- The status of the focus sensor [as listed in ISR100120 on page 71]
- The status of the wavefront sensor [as listed in ISR110070 on page 73]
- A "quick look" display showing science data and any quality control data (if any) calculated on the fly.

**How to test:** To be tested by reviewing the software design.

## *7.2 Instrument Controller Functional Requirements*

**ISR020010 All camera mechanisms shall be fully controllable from software**

**Need:** Requirement **Source: TS 6.1.1, 4.13.2, 4.15.4, 5.4.5**

**Description:** All the mechanisms contained in each camera should be controllable from software, i.e. no mechanism should need manual intervention from the telescope operator.

**How to test:** To be tested by reviewing the software design.

**ISR020020 The software shall accommodate changing cameras such that manual operations are minimised**

**Need:** Requirement **Source: TS 6.1.2, 7.3.5**

**Description:** The software should automate, where possible, the procedures that need to be carried out during and after a camera change.

**How to test:** To be tested by reviewing the software design.

**ISR020030 The software shall support concurrent operations where these are allowed by the ESO philosophy**

**Need:** Requirement **Source: TS 4.16.2/2, 5.2.4/4**

**See also: OCDD 4.1, 4.2**

**Description:** To maximise the observing efficiency, the software should allow independent operations, such as a telescope slew, instrument reconfiguration and detector readout/data storage to be executed in parallel wherever possible. This requirement is contrained by the ESO philosophy of not beginning an exposure until the previous exposure has been successfully saved to permanent storage, so it may not be possible to overlap operations with detector readout/data storage. Overlapping detector readout with other operations also assumes there is no electronic interference between the telescope and instrument mechanisms and the detector electronics.

**How to test:** To be tested by reviewing the software design and by trying out the concurrent operations that the software is designed to support.

**ISR020040** **It shall be possible to run both camera controllers simultaneously**

**Need:** Requirement **Source: TS 6.1.2, 7.3.4, 7.3.5**

**Description:** Only one instrument is mounted on the telescope at any one time. While observing with the mounted instrument, it must be possible to control the other instrument to allow engineering activities to be carried out ([AD3] TS 06.100).

**How to test:** To be tested by reviewing the software design and by running both instrument controllers at the same time.

**ISR020050** **The camera controllers shall be independent**

**Need:** Requirement **Source: TS 6.12**
**See also: SRD 4.3.3/4**

**Description:** It must be possible to observe with either instrument when the other instrument has been removed for maintenance. This means the visible and infrared controllers must be independent.

**How to test:** To be tested by reviewing the software design and by running one instrument controller while the other instrument is switched off.

**ISR020060** **It shall be possible to run any of the camera controllers stand-alone**

**Need:** Requirement **Source: TS 6.1.2/2, 7.3.5.3**

**Description:** It must be possible while developing and testing an instrument to be able to run its control software stand-alone — i.e. isolated from the rest of the VISTA software. This will be necessary especially if an instrument is developed and built in a remote laboratory. Appropriate test software should be provided so that the interfaces between the instrument software and VISTA software can be tested before delivery.

**How to test:** To be tested by reviewing the software design and by running one instrument controller while the other instrument is switched off.

**ISR020070 Both cameras shall be capable of being monitored continuously**

**Need:** Requirement **Source: TS 7.3.4**
**See also: SRD 4.3.3/1, OCDD 3.4**

**Description:** The temperatures and other important parameters of both cameras should be monitored, even when the cameras are not currently in use. This is to avoid loss of time due, for example, to a cryostat warming up and so not being ready for its next planned use. SRD 4.3.3/1 specifies switching cameras in one day, implying the second camera is ready for use — e.g. already cold.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR020080 Filter identification shall be carried out by software**

**Need:** Requirement **Source: TS 5.2.4, 5.3.3**
**See also: SRD 4.3.2/1**

**Description:** Each physical filter will carry a machine-readable unique identifier. The software is responsible for using this to identify the filters. The instrument should be designed, if possible, so that the identifier read at any moment is that of the filter in the beam.

**How to test:** To be tested by reviewing the software design and by identifying the filters contained in each instrument.

**ISR020090 The operator shall be warned when the camera throughput is degraded**

**Need:** Requirement **Source: TS 4.12.2, 6.1.6**
**See also: OCDD A.1.3**

**Description:** The operator should be warned in some way when the throughput of an instrument is deliberately degraded, such as by inserting a neutral density filter into the beam (TS 4.10.2). This could be achieved, for example, by careful design of the real time display.

**How to test:** To be tested by reviewing the software design and by selecting a neutral density filter.

**ISR020100 The software shall meet the error budget necessary for filter devices**

**Need:** Requirement **Source: TS 5.2.4/1, 5.3.3/3**
**See also: SRD 4.3.2/9**

**Description:** The filter positioning devices must be sufficiently repeatable that any dirt, dust or marks on the filter will be in the same position on a science frame and the corresponding flat-field frame. This is necessary for VISTA to meet its system image quality requirement (TS 4.9). The device control software must allow the mechanisms to meet this target by keeping within the specified error budget.

**How to test:** To be tested by reviewing the software design, by mechanical tests on the filter assembly, and finally by measuring the repeatability of flat-field exposures made through the same filter selected on different occasions.

**ISR020105 The software shall not prevent filter devices achieving their minimum filter change time requirement**

**Need:** Requirement **Source: TS 5.2.4, 5.3.3**

**Description:** It must be possible to change filters on the visible camera within 25 seconds, or within 60 seconds if the filters are on the same carousel. It must be possible to change filters on the infrared camera within 60 seconds, or within 25 seconds for adjacent filters. The control software must not introduce unnecessary overheads that prevent this minimum filter change time from being achieved.

**How to test:** To be tested by selecting various filters and timing how long the reconfiguration takes.

**ISR020110 Excess illumination of detector during filter changes shall be avoided**

**Need:** Requirement **Source: TS 4.12 (sensitivity)**
**See also: SRD 4.3.2/8**

**Description:** Depending on the final design of the mechanisms, the Instrument Controller might have to sequence filter changes in such a way that a shutter is closed, a separate blanking filter is present, or the direction of travel of the filter wheel is carefully chosen to avoid temporary overillumination of the detectors affecting the following observation.

**How to test:** To be tested by reviewing the software design and by running through worst-case filter change scenarios.

**ISR020120 The software shall be capable of making automatic focus adjustments when a filter is changed**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7**
**See also: OCDD**

**Description:** When the filter in the beam is changed, the instrument software should have the ability to automatically adjust the focus to compensate for the optical properties of the new filter. *This requirement will be needed if the autofocus beam does not pass through the science filter.*

**How to test:** To be tested by reviewing the software design, by checking the focus demands made when each filter is selected, and finally by comparing the image defocus measured through different filters.

**ISR020130 Where information is available from hardware this shall be used to check whether the target camera configuration has been achieved**

**Need:** Requirement **Source: TS 7.2, 7.3.4/1**
**See also: SRD 6 (survey speed)**

**Description:** If the location of camera components can be sensed from the hardware, the instrument software must use this information to verify that mechanisms have achieved their target configuration. For example, if the filter positioning device does not end up in the correct position it must be possible for the software to deduce this straight away rather than deduce the fault later from the data quality. In practice this means the filter device needs to have some kind of feedback, such as in-position microswitches or identification devices that will not read when the filter is out of position. This requirement arises from the need to maximise observing efficiency and survey speed.

**How to test:** To be tested by reviewing the software design and by testing the software's response to a stalled motor and/or disabled in-position switch.

**ISR020140 The camera and telescope configuration shall be checked before starting an observation**

**Need:** Requirement **Source: TS 4.16.2/1, 7.2, 7.3.4/1**
**See also: SRD 6 (survey speed)**

**Description:** Problems that would result in invalid data should be checked and reported before allowing an observation to start. It is not acceptable to discover such errors by examining the data at the end of the night.
Confirmation should be sought from the telescope operator before starting an observation when any of the following conditions are true:
- An attempt to start an exposure when there is insufficient permanent storage space to store the data (TS 4.16.2/1).
- An attempt to start an exposure that isn't a bias with a zero exposure time.
- An attempt to start an exposure that isn't a bias or dark with the shutter closed (visible) or with a cold blocking filter in place (infrared).
- An attempt to start a science exposure with the wrong filter in place (if the filter identifier is readable).
- An attempt to start an exposure when any parts of the instrument (with the possible exception of the ADC) are moving or are not in their expected position. (If the hardware allows this — see previous requirement).
- An attempt to start a science exposure with the dome closed or vignetted, or with the mirror covers in place.
- An attempt to start an exposure while the telescope is slewing and not yet in position.
- An attempt to start an exposure when an interlock is reported by the hardware (TS 4.17/7).

This requirement arises from the need to maximise observing efficiency and survey speed.

**How to test:** To be tested by reviewing the software design and by selecting various illegal instrument configurations.

**ISR020150 Faults shall be reported to the telescope operator as soon as they are detected**

**Need:** Requirement **Source: TS 6.1.6, 7.3.4/1**
**See also: SRD 6, 7.5, OCDD 5.4**

**Description:** Any error conditions that indicates a system failure or a possibility of a loss of data quality should be reported to the telescope operator as soon as they occur. For example, the following conditions should be reported as soon as they are detected. Some of the conditions (*) are predictable and should be reported as a warning *before* they occur:
- A command is rejected by the instrument software.
- The autoguider loses its lock on the guide star [see ISR100110 on page 71].
- The seeing monitor detects seeing outside the acceptable range.
- The atmospheric transparency drops below a threshold value (OCDD 5.4).
- The airmass drifts outside its acceptable range (*).
- Telescope enters the zenith blind spot (*).

- The detector temperature monitor detects a temperature outside the acceptable range.
- A failure is reported by the telescope controller.
- A failure is reported by the instrument controller.
- A failure is reported by the detector controller.
- An error is reported while transferring data from the detector controller.
- An error is reported while saving the data to disk.
- An interlock is reported (TS 4.17/6).

**How to test:** To be tested by reviewing the software design and by inducing various system faults and observing the response.

**ISR020160 A record of faults and significant events shall be written to the end of night observing log as soon as they occur**

**Need:** Requirement **Source: TS 6.1.5, 7.3.4/1**
**See also: SRD 7.5/3**

**Description:** A record of faults and significant events must be written to an end of night observing log. Each event must be tagged with a time stamp in UT. Sufficient information should be provided to provide the telescope operator with a summary of the night's operations and provide an engineer with background information about any faults that may have happened. Any fault that the system reported to the telescope operator (as listed in the previous requirement) is a significant fault. Significant events include:
- Dome opened
- New observation selected by scheduler
- Telescope slews to new target
- Telescope offsets to new dither position
- Autoguider locks onto guide star [see ISR100110 on page 71]
- Instrument mechanisms reconfigured
- Instrument begins exposure
- Instrument competes exposure
- Data saved to disk
- Telescope operator records a comment
- Interlock reported by hardware (TS 4.17/6).
- Dome closed

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR020170 A record of observing conditions shall be written to the end of night observing log and a summary made available by noon the following day**

**Need:** Requirement **Source: TS 5.5.4, 6.1.5, 6.1.7**

**See also: SRD 7.5/3**

**Description:** In addition to logging faults and significant events, the end of night observing log must also contain a record of the observing conditions measured throughout the night. Examples of this information are:

- Environmental conditions (temperature, humidity, wind speed, etc.)
- The seeing and sky brightness measured by the seeing.
- The FWHM of the guide star image and the telescope focus correction determined by the optical sensing system [see also ISR100090 and ISR100100 on page 70].
- Wavefront errors determined by the optical sensing system [see also ISR110060 on page 73].

The update rate should be sufficiently frequent (e.g. every few seconds) to allow several samples to be saved during a typical exposure, and allow the trends in atmospheric conditions during the night to be plotted. *NOTE: The worst and typical atmospheric seeing is independently written to the FITS header of each observation [see ISR040140 on page 48].*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR020175 A record of significant engineering parameters shall be written to the end of night observing log**

**Need:** Requirement **Source: TS 5.5.4, 6.1.5**
**See also: SRD 7.5/3**

**Description:** The end of night observing log must contain sufficient information to allow an observation to be reproduced. Besides containing a description of the instrument configurations adopted and the exposures made it must also contain the following information:

- The software version numbers.
- The telescope pointing coefficients (or a reference to those coefficients).
- Instrument setup parameters and coefficients (or a reference to that information).

If the engineering coefficients are extensive, are under change control and do not change very often it may be sufficient to supply a reference to the version number of the coefficients used.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR020180 The end of night observing log shall have a common data format**

**Need:** Requirement **Source: TS 6.1.5**
**See also: SRD 7.5/3**

**Description:** The end of night observing logs generated by the visible and infrared instrument software must be in a common format so that the same browsing and analysis tools can be used for both.

**How to test:** To be tested by reviewing the software design.

**ISR020190 The software shall respond to interlocks reported by the hardware**

**Need:** Requirement **Source: TS 4.17**

**Description:** If the instrument hardware reports an interlock the software shall respond as follows:
- The event shall be reported to the operator and logged as a fault (see ISR020150 and ISR020160) (TS 4.17/6).
- The software must shut down the device to which the interlock refers (i.e. stop any outstanding commands for that device and not accept any new commands) (TS 4.17/7).
- The software must not resume any interrupted commands or restart any motion automatically when the interlock signal is cancelled (TS 4.17/8).

NOTE: The reponse to a VISTA interlock must never depend on software (TS 4.17/6). It is assumed that an interlocked device will already have been disabled by the hardware before the software responds to the signal. The primary purpose of the software response is to inform the operator, log the fault, and prevent further attempts to operate the interlocked device.

**How to test:** To be tested by reviewing the software design and by inducing interlock signals.

## *7.3 Detector Controller Functional Requirements*

Although the detector controller is not part of the scope of this work, the VISTA instrument software places these requirements on the detector controller.

**ISR030010 It shall be possible to abort an exposure started by mistake**

**Need:** Requirement **Source: TS 4.13.2, 4.15.4.1, 4.15.4.2**
**See also: SRD 6 (survey speed)**

**Description:** If an exposure is started by mistake it must be possible to abort that exposure quickly and restart a new one. You should not have to wait for the requested exposure time to complete. This requirement arises from the need to maximise observing efficiency and survey speed.

Note: This requirement is also necessary to allow the telescope operator to abort and restart an observation if a serious fault is reported while the observation is in progress.

**How to test:** To be tested by reviewing the software design and by attempting to abort a long exposure.

**ISR030015** **It shall be possible to make exposures of any duration specified between 1s (0.5s goal) and 1 hour, and the actual exposure time must be within to 0.1s or 1% of that specified, whichever is the larger.**

**Need:** Requirement **Source: TS 4.15.1, 4.15.2/1**

**Description***:* The detector controller must be capable of making exposures in the range 1 second (0.5 second goal) to 1 hour. The actual exposure time must be within 0.1s or 1% of that specified, whichever is the larger.

**How to test:** To be tested by requesting various exposure times within the allowed range and verifying the actual exposure time used is within the allowed tolerance.

**ISR030020** **The total exposure time shall be stored in the data header to an accuracy of 0.01s or 0.25% of the actual exposure time, whichever is larger.**

**Need:** Requirement **Source: TS 4.15.2/2**

**Description:** The detector controller must be capable of measuring the actual exposure time and storing it into the data header with the specified accuracy.

**How to test:** To be tested by comparing the exposure time stored in the data header to an exposure time measured using independent timing equipment attached to the shutter.

**ISR030030** **The detector controller software shall provide sufficient information to permit reconstruction of the absolute UT of mid exposure at each pixel within 0.1 seconds.**

**Need:** Requirement **Source: TS 4.15.4**
**See also: SRD 4.6.6/5**

**Description:** The absolute timing of each exposure needs to be known as a function of pixel position. This may involve providing with each exposure information on the timing of the passage of the shutter across the detector during that exposure or, if the shutter is sufficiently repeatable, providing separate calibration information showing how the shutter timing varies for each detector pixel, together with an accurate timing of the beginning of the shutter motion for one particular reference pixel. The information should be sufficiently accurate to permit reconstruction of the absolute time of the exposure mid point to within 0.1 seconds.

**How to test:** To be tested by reviewing the software design and by observing a phenomenon, such as a stellar occultation, whose UT is accurately known. Can also be tested by making independent timing measurements on the shutter assembly.

**ISR030035** **Using the visible camera, it shall be possible the make a single exposure with multiple shutter operations for diagnostic purposes.**

**Need:** Requirement **Source: TS 5.2.5/5**

**Description:** The visible camera must have the ability to keep the detectors integrating while the shutter makes several open/close operations. This ability is needed by the shutter linearity calibration check described in ISR050180.

**How to test:** Carry out the shutter linearity calibration check.

**ISR030040** **Using the visible camera, it shall be possible to start a new exposure within 40 seconds of the completion of the previous exposure.**

**Need:** Requirement **Source: TS 4.15.4.1/1, 5.2.7.1, 5.5.1.3**
**See also: SRD 6.4**

**Description:** Given the ESO philosophy of not starting a new exposure until the data from the previous exposure has been successfully saved to permanent storage (see ISR020030), this requirement means that the visible detectors must all be read out and saved to permanent storage within 40 seconds (ISR040005). It is a goal for this readout speed to be as fast as reasonably possible so that VISTA can work efficiently without violating the ESO philosophy.

**How to test:** To be tested by reviewing the software design, by timing the readout and by attempting to start a new exposure 40 seconds after the previous one has finished.

~~ISR030050 Deleted.~~

~~ISR030060 Deleted.~~

**ISR030070 Using the infrared camera, it shall be possible to start a new exposure within 5 seconds of the completion of the previous exposure**

**Need:** Requirement **Source: TS 4.15.4.2/1, 5.3.6.1/6**
**See also: SRD 6.4**

**Description:** Given the ESO philosophy of not starting a new exposure until the data from the previous exposure has been successfully saved to permanent storage (see ISR020030), this requirement means that the infrared detectors must all be read out and saved to permanent storage within 5 seconds (ISR040065). TS 5.3.6.1/6 also requires that each read time should take no longer than 1 second at maximum well depth.

**How to test:** To be tested by reviewing the software design, by timing the readout and by attempting to start a new exposure 5 seconds after the previous one has finished.

~~ISR030080 Deleted.~~

**ISR030090 Using the infrared camera, it shall be possible to execute and process, prior to data storage, multiple readouts per exposure.**

**Need:** Requirement **Source: TS 4.15.4.3**
**See also: OCDD A.2.6**

**Description:** The infrared detector controller must be capable of operating in the following readout modes:
- Reset/read/read — Double correlated sampling where the array is reset, a read is made immediately and a second read is made after a predetermined delay. In this case subtracting the first read from the second gives the data frame.
- Read/reset/read — sequences as specified in the OCDD A.2.6.

During an exposure it shall be possible to perform individual readouts at a rate of one every 10 seconds.

**How to test:** To be tested by reviewing the software design and by exercising all the possible readout modes.

**ISR030100 The infrared camera shall be capable of making a rapid sequence of exposures.**

**Need:** Requirement **Source: TS 4.15.4.4**
**See also: OCDD A.2.6**

**Description:** The infrared detector controller must be capable of making a rapid sequence of short exposures such that the delay between completing one exposure and starting the next shall be less than 1 second. It shall be possible to acquire data and store exposures at a rate of one in every 10 seconds for raw data and one in every 20 seconds for the multiple readout data described in ISR030090. The number of exposures in the sequence shall be defined in advance.

This requirement implies that the infrared detectors must at the same time have a fast readout speed, fast processing speed, and a buffer of sufficient size to store all the intermediate frames while they are waiting to be processed and stored.

**How to test:** To be tested by reviewing the software design and by making a rapid sequence of exposures.

**ISR030110** **The infrared camera detector shall have an active temperature control mechanism.**

**Need:** Requirement **Source: TS 5.3.6.4**

**Description:** The infrared detector must be maintained at its optimum operating temperature. The infrared detector controller must have a means of controlling this temperature. The detector controller software will at least need the ability to configure the target temperature and monitor the current temperature.

**How to test:** To be tested by measuring the detector characteristics, such as the read noise, and monitoring the detector temperature.

## *7.4 Data Handling Requirements*

### 7.4.1 Data rate and volume

**ISR040005** **Visible data handling software shall be capable of storing one full frame of data within 40 seconds.**

**Need:** Requirement **Source: TS 4.15.4.1/2**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** The data handling software must be capable of receiving and storing one full frame of visible data within 40 seconds. Each frame can consist of 50 detectors of 4608x2048 pixels each, which corresponds to 471859200 pixels. If 2 bytes are used to store each pixel one frame in 40 seconds corresponds to a data rate of **23.3 MB/second**.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040020** **Visible data handling software shall be capable of dealing with a sustained data rate of one full frame every 60 seconds**

**Need:** Requirement **Source: TS 4.15.4.1/2**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** If exposures are taken at their expected maximum rate, the data handling software needs to be capable of receiving and storing one full frame of visible data every 60 seconds. Each frame can consist of 50 detectors of 4608x2048 pixels each, which corresponds to 471859200 pixels. If 2 bytes are used to store each pixel one frame every 60 seconds corresponds to a data rate of **15.7 MB/second**.

**How to test:** To be tested by reviewing the software design and by demonstration.

~~ISR040020 Deleted~~

**ISR040030** **There shall be sufficient on-line data storage available to store one full frame of visible data every 60 seconds sustained for 14 hours**

**Need:** Requirement **Source: TS 4.15.4.1/2**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** There must be sufficient space to store the data from one exceptional night where a data rate of one full frame of visible data every 60 seconds is sustained for 14 hours. This corresponds to 840 frames of 944 MB each, making a minimum requirement of **793 GB**.

**How to test:** To be tested by demonstration.

~~ISR040040 Deleted.~~

**ISR040050** **There shall be sufficient on-line data storage available to store the visible data from two typical nights**

**Need:** Requirement **Source: TS 4.16.5**
**See also: OCDD A.3, [RD2]**

**Description:** There must be sufficient space to store the data from two typical nights. A typical night generates 190 GB of visible data, so to fulfil this requirement there should be at least **380 GB** of on-line storage.

**How to test:** To be tested by demonstration.

**ISR040060 There shall be sufficient near-line data storage available to store the visible data from 30 typical nights**

**Need:** Requirement **Source: TS 4.16.6, 5.5.2**
**See also: OCDD A.3, [RD2]**

**Description:** It must be possible to retrieve quickly the data from the last 30 nights of observing from a near-line data storage medium (e.g. juke box DVD, tape library etc.) at Paranal. This requires a minimum of **6 TB** of storage for visible data.

**How to test:** To be tested by demonstration.

**ISR040065 Infrared data handling software shall be capable of storing one full frame of infrared data within 5 seconds**

**Need:** Requirement **Source: TS 4.15.4.2/2, 5.5.1.4**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** The data handling software must be capable of receiving and storing one full frame of visible data within 5 seconds. Each frame can consist of 16 detectors of 2048x2048 pixels each, which corresponds to 67108864 pixels. If 4 bytes are used to store each pixel (in the worst case) one frame every 10 seconds corresponds to a data rate of **53.8 MB/second**.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040070 Infrared data handling software shall be capable of dealing with a sustained data rate of one full frame every 10 seconds**

**Need:** Requirement **Source: TS 4.15.4.2/2, 5.5.1.4**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** If exposures are taken at their maximum sustained rate, the data handling software needs to be capable of receiving and storing one full frame of infrared data every 10 seconds. Each frame can consist of 16 detectors of 2048x2048 pixels each, which corresponds to 67108864 pixels. Only 2 bytes are used to store each pixel during sustained operation, so one frame every 10 seconds corresponds to a data rate of **13.4 MB/second**.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040080 There shall be sufficient on-line data storage available to store one full frame of infrared data every 10 seconds sustained for 14 hours**

**Need:** Requirement **Source: TS 4.15.4.2/2**
**See also: OCDD 2.7, A.3, [RD2]**

**Description:** There must be sufficient space to store the data from one exceptional night where a data rate of one full frame of infrared data every 10 seconds is sustained for 14 hours. This corresponds to 5040 frames of 134 MB each (assuming 2 byte words for sustained use), making a minimum requirement of **676 GB**.

**How to test:** To be tested by demonstration.

**ISR040090 There shall be sufficient on-line data storage available to store the infrared data from two typical nights**

**Need:** Requirement **Source: TS 4.16.5**
**See also: OCDD A.3, [RD2]**

**Description:** There must be sufficient space to store the data from two typical nights. A typical night generates 400 GB of infrared data, so to fulfil this requirement there should be at least **800 GB** of on-line storage.

**How to test:** To be tested by demonstration.

**ISR040100 There shall be sufficient near-line data storage available to store the infrared data from 30 typical nights**

**Need:** Requirement **Source: TS 4.16.6**
**See also: OCDD A.3, [RD2]**

**Description:** It must be possible to retrieve quickly the data from the last 30 nights of observing from a near-line data storage medium (e.g. juke box DVD, tape library etc.) at Paranal. This requires a minimum of **12 TB** of storage for infrared data.

**How to test:** To be tested by demonstration.

**ISR040110 Visible and infrared storage space can be concurrent and shall allow for engineering work**

**Need:** Requirement **Source: TS 5.5.1.2, 7.3.4**
**See also: OCDD A.3, [RD2]**

**Description:** The visible and infrared cameras must operate independently (ISR 020040). Although only one instrument will be used for science at any one time, there is a requirement for neither instrument to affect the other, and for engineering work to be possible on one instrument while the other is collecting science data (ISR 020050). To achieve this requirement the instruments will be controlled from separate work stations with their own separate data storage (see TS 5.5.1.2). The following table summarises the various data storage and data rate requirements (see also section 7.1 of [RD2]).

| **Data Storage Requirement for** | *Visible Camera* | *Infrared Camera* |
|---|---|---|
| One exceptional night (on-line) | 793 GB | 676 GB |
| Two typical nights (on-line) | 380 GB | 800 GB |
| 30 nights near-line (near-line) | 6 TB | 12 TB |

| **Data Rate Requirement for** | *Visible Camera* | *Infrared Camera* |
|---|---|---|
| Data readout and storage of one frame | 23.3 MB/s | 13.4 MB/s |
| Sustained data acquisition | 15.7 MB/s | 53.8 MB/s |

**How to test:** To be tested by by demonstration.

### 7.4.2 Data format

**ISR040120 Data shall be saved to FITS files which conform to ESO standards**

**Need:** Requirement **Source: TS 4.16.3, 5.5.1.1, 5.5.3.1/1**
**See also: SRD 7.1/1, OCDD 2.8, [AD4]**

**Description:** In order to be exportable to the ESO data archive, data must be saved to files adhering to the ESO interpretation of the FITS standard, as described in the *ESO Data Interface Control Document* [AD4] which specifies things such as how data frames from array mosaics map onto FITS files. Mandatory normal FITS headers plus ESO hierarchical FITS headers are also specified.
There should be one separate FITS file for each exposure and a separate FITS extension for each detector (which allows each detector to have its own World Coordinate System).

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040130 The data should be easily importable by the UK Data Centre**

**Need:** Goal **Source: [NEW]**

**Description:** The data format should be designed if possible to make it easily importable by the UK Data Centre, where this is allowed by ESO standards. *(If it is not possible to satisfy this requirement within the ESO standards then ESO-to-UK data conversion utilities will be needed, but this is beyond the scope of the VISTA instrument software).*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040132 Data from the visible camera shall be saved in a raw form without any preprocessing**

**Need:** Requirement **Source: TS 4.16.1.1**

**Description:** Visible data will be saved to permanent storage in the same format as read from the detectors, 2 bytes per pixel.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040134 Data from the infrared camera shall be saved in a limited choice of formats**

**Need:** Requirement **Source: TS 4.16.1.2**

**Description:** Infrared data will be saved to permanent storage in one of the following formats:

- Raw data, with or without differencing, 2 bytes per pixel.
- Coadded data, 4 bytes per pixel (see ISR040280).
- Reduced read/reset/read, 4 bytes per pixel.

Any set of data will be stored in only one of these formats at a time.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040140 FITS headers must contain sufficient information for an exposure to be completely identified and its data reduced**

**Need:** Requirement **Source: TS 4.16.3, 5.5.3.1/2**
**See also: OCDD 2.8**

**Description:** This requirement means that sufficient information should be contained in the FITS header to allow the data processing software to determine how the observation was made and how the data needs to be processed. Information can be extracted directly from the FITS header or looked up in a database using something from the FITS header as a key, but it should not be necessary to interrogate any VISTA control systems. The FITS headers should therefore contain at least the following information (OCDD 2.8):

- Administrative information, including:
  - A label indicating "Cerro Paranal Observatory at NTT peak" as the observatory
  - A standard (e.g. slaLib-recognised) label indicating VISTA as the telescope
  - A label indicating VISTA as the data source
  - A label for the instrument (visible or infrared camera)
  - Observatory latitude, longitude and height above sea level
  - A string indicating proprietary data rights (e.g. data of expiry of data rights)
  - The unique science programme identifier (defined by committee)
  - The science programme title
  - The unique observation identifier (fixed regardless of schedule)
  - A unique run number, strictly increasing with time
  - The nightly run number
  - The observation title (defined by scientist)
  - An externally defined identifying string (e.g. grid number or CDS-resolvable name)
  - Whether science, calibration or engineering data.
  - Type of data (bias, dark, dome flat, sky flat, standard field, science field, etc.)
  - Zero or more comment strings supplied by the software or by the telescope operator
  - A unique local identifier for the whole night (e.g. local calendar date at the start of the night). This is used to group together observations made on the same night.
  - Versions of the telescope and instrument controller software (sufficient information to be able to cross reference a change log)
- Instrument configuration information
  - Identifier(s) for the filter(s) in the beam (several keywords may be needed, e.g. name of passband, name of photometric system and filter ID)
  - Position of filter wheel
  - Position angle of ADC at start, end and mid point of exposure (visible)
  - Whether shutter was open or closed (visible)
  - Whether cold blocking filter was in place (infrared)
  - A string summarising the instrument health (e.g. GOOD or BAD. Can be supplemented by operator comment strings).

- Observation timing information, including:
  - UT and MJD dates of observation (DATE-OBS and MJD-OBS).
  - Requested UT range for observation (if specified)
  - Actual UT of start, end and mid point of observation. (If shutter is opened and closed more than once, the mid point may not always be half way between the start and end times).
  - Local sidereal time at start of observation
  - Requested exposure time on sky in seconds
  - Actual exposure time on sky in seconds
  - Actual exposure time on dark current in seconds
  - Shutter motion coefficients sufficient to determine the shutter open and shutter close time as a function of detector pixel (if available)
- Pointing and tracking information, including:
  - Reference frame for all celestial coordinates (e.g. FK5)
  - Requested RA, Dec, Equinox, Epoch and Proper Motion of nominal field centre
  - Actual RA, Dec, Equinox and Epoch of nominal field centre
  - Actual RA, Dec, Equinox and Epoch of telescope pointing
  - Requested non-sidereal tracking rate in arcsec/minute (if any)
  - Actual non-sideral tracking rate in arcsec/minute (if any)
  - Position angle of instrument Y axis (relative to the telescope and relative to the sky) at the start, end and mid exposure
  - Zenith distance, azimuth and hour angle of field at start, end and mid exposure.
  - Telescope focus
- Dithering information, including:
  - Keyword to group together multiple exposures at a set of dither positions (e.g. ING's RUNSET keyword)
  - Offsets from central dither position in arcseconds of RA, Dec and camera x,y pixels
- Observing conditions, including:
  - Requested acceptable range of airmass for observation
  - Worst and effective airmass during exposure
  - Requested maximum lunar phase
  - Actual lunar phase and angular distance of moon from telescope axis
  - Requested acceptable range of seeing for observation
  - Worst and effective seeing measurement during exposure (SRD 7.1, TS 10.170)
  - (goal) Requested acceptable range of transparency for observation
  - (goal) Worst and effective transparency during exposure (TS 10.170)
- Optical sensing information, including:
  - RA, Dec for each guide star
  - Pixel coordinates of each guide star on guider chip
  - Mean guide error during observation
  - RA, Dec for each focus star
  - Pixel coordinates of each focus star on focus sensor chip

  - Mean focus correction during observation
  - RA, Dec for each WFS star
  - Pixel coordinates of each WFS star on WFS chip
- Environmental information at time of observation (SRD 7.1, TS 10.170):
  - Temperature of telescope tube
  - Temperature of mirrors
  - Temperature of air inside the dome
  - Temperature of air outside the dome
  - Humidity
  - Barometric pressure
  - Wind speed and direction
  - Cloud cover
  - Atmospheric extinction
- Detector information, including:
  - Approximate World Coordinate system information for each detector chip in sky coordinates (SRD 4.5.1, OCDD 6.1.5)
  - Physical identifier and type for each detector chip
  - Logical position of each detector chip within the mosaic
  - Number of pixels and overscans etc. for each detector chip
  - Pixel size for each detector chip
  - Location of each detector chip in the focal plane (i.e. a map of the layout of the detector chips and the gaps between them — sufficient information to lay out a quick look display)
  - Read noise and gain setting for each chip
  - Saturation value for each detector chip

NOTE: The exact contents of the data header needs to be specified in an *VISTA Instrument Software to Offsite Data Export* Data Dictionary (see ISR070010 on page 67) and may evolve, subject to change control, during the software design

**How to test:** To be tested by reviewing the software design and data disctionary, and by demonstration.

### 7.4.3 Generation of calibration data

**ISR040150** **The data processing software shall generate a bad pixel mask when requested by the telescope operator or by the scheduler.**

**Need:** Requirement **Source: TS 5.5.4, 6.1.3**
**See also: OCDD 6.1.3**

**Description:** The data processing software will generate a bad pixel mask on demand from a specified set of calibration exposures (e.g. dome flats). Bad pixels can be detected, for example, by looking for spikes in the data or for

pixels containing known garbage values. More than one exposure should be examined to distinguish one-off cosmic ray events from genuine bad pixels (which are expected to be found in all exposures). This will be needed after a camera change or whenever a data quality check suggests the bad pixel map may have changed.
*NOTE: The above algorithm is a suggestion. The exact algorithm is to be specified during the software design.*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040160** **The data processing software shall generate a master bias frame when requested by the telescope operator or by the scheduler.**

**Need:** Requirement **Source: TS 6.1.3**
**See also: OCDD 6.1.1, 6.2.1**

**Description:** The data processing software will generate a master bias frame on demand by combining together a specified series of visible bias observations. NOTE: Bias frames are not needed for infrared observations.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040170** **The data processing software shall generate a twilight flat-field when requested by the telescope operator or by the scheduler.**

**Need:** Requirement **Source: TS 6.1.3**
**See also: OCDD 6.1.4**

**Description:** The data processing software will generate a twilight flat-field on demand by combining together several specified exposures of the twilight sky.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040180** **The data processing software shall generate an infrared sky-flat when requested by the telescope operator or by the scheduler.**

**Need:** Requirement **Source: TS 6.1.3**
**See also: OCDD 6.2.4**

**Description:** The data processing software will generate an infrared sky-flat on demand by taking the median of a specified series of sky exposures made with small dither offsets.

**How to test:** To be tested by reviewing the software design and by demonstration.

### 7.4.4 Quality control information

**ISR040190 Bad pixels should be checked for occasionally and the results made available by noon the following day.**

**Need:** Goal **Source: TS 5.5.4**
**See also: SRD 7.5, OCDD 6.1.3**

**Description:** The data processing software should examine a representative sample of the exposures made during the night (e.g. the dome flats) and determine the location of any bad pixels on each detector (see ISR050124 on page 63). The result should be compared with the current bad pixel mask and any differences logged and reported to the operator by noon the following day. The frequency of this procedure is variable. This procedure does not need to be done every night.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040200 The detector dark current shall be calculated occasionally from the data and made available by noon the following day.**

**Need:** Requirement **Source: TS 5.5.4**
**See also: SRD 7.5**

**Description:** The dark current for each detector should be estimated from each of the dark frames made during the night (including afternoon calibrations) and reported by noon the following day (see ISR050126 on page 63). The software should compare the dark frames and determine any dark current trends, reporting anything out of range to the operator. This should detect any problems that were not already detected by the cryostat temperature sensor or vacuum sensor. The frequency of this procedure is variable. The procedure does not need to be done every night.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040210 An estimate of the system noise shall be calculated nightly from the data and made available by noon the following day.**

**Need:** Requirement **Source: TS 5.5.4**

**Description:** The system noise should be estimated by examining the fluctuation in the background in each of the dark frames made during the night (including afternoon calibrations) and reported by noon the following day. The software should compare the dark frames and determine any system noise trends, reporting anything out of range to the operator.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040215** **An estimate of the sky brightness level shall be calculated nightly from the data and made available by noon the following day.**

**Need:** Requirement **Source: TS 5.5.4**

**Description:** The sky brightness should be estimated by determining the sky background level in the science exposures made during the night and reported by noon the following day. The software should summarise any trends in the sky background level during the night, reporting anything out of range to the operator.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040220** **A mean point spread function (PSF) shall be calculated nightly from the data and made available by noon the following day.**

**Need:** Requirement **Source: SRD 4.4.1/3, 4.4.2/1, TS 5.5.4**
**See also:**

**Description:** The software should take a representative sample of the science exposures made during the night (e.g. sufficient to find at least one point source on each detector) and locate the brightest point sources near the centre and near the edge of each detector. A point spread function should be determined for each source and an average point spread determined for point sources at the centre and the edge of each detector. The report should correlate the PSFs with the atmospheric seeing measurements made at the same time.

The software should allow for the possibility of there not being any suitable point sources imaged on some of the detectors, so it should allow the report to contain gaps.
*NOTE: The above algorithm is a suggestion. The exact algorithm is to be specified during the software design.*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040230** **An estimate of the System Image Quality parameter shall be calculated nightly from the data and made available by noon the following day**

**Need:** Requirement **Source: TS 4.9, 5.5.4**
**See also: SRD 4.4, 7.5**

**Description:** The TS in section 4.9 (and the SRD in section 4.4) defines the System Image Quality (SIQ) as the contribution to the point source image size made by the detector size, sampling, optical system image quality, tracking, guiding, thermal expansion, flexure and dome seeing; but not including the free atmospheric seeing. SIQ is defined as

$$\text{SIQ} = \max(50\%\ \text{EED},\ 80\%\ \text{EED}/1.54)$$

where 50% EED is the 50% encircled energy diameter. The SIQ can be estimated from the point spread functions (see previous requirement) by deconvolving them with the atmospheric seeing reported at the same time as the observation.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040240** **The data processing software may run a copy of the data reduction pipeline at Cerro Paranal**

**Need:** Goal **Source: [NEW]**
**See also: SRD 7.5**

**Description:** It is a goal to run the data reduction pipeline at Paranal on a subset of the data to provide more accurate quality control information.

**How to test:** To be tested by demonstration.

**ISR040250** **An approximate photometric zero point for each observation shall be estimated nightly from the data and made available by noon the following day.**

**Need:** Requirement **Source: TS 5.5.4**
**See also: OCDD 6.1.6**

**Description:** The photometric zero point should be estimated to about 10% accuracy from the photometric standards observed during the night. This can

be done by determining the magnitudes for these sources from the standard star fields, using a best guess for the atmospheric extinction, and comparing the results with their magnitudes quoted in a photometric catalogue. This photometric zero point can then be used to estimate the system sensitivity.
*NOTE: The above algorithm is a suggestion. The exact algorithm is to be specified during the software design.*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040260** **The accurate photometric zero point for each observation may be calculated nightly from the data and made available by noon the following day.**

**Need:** Goal **Source: TS 5.5.4**
**See also: OCDD 6.1.6**

**Description:** It is a goal for an accurate photometric zero point to be determined from the photometric standards observed during the night. This can be done by determining the magnitudes for these sources from the calibrated science data, taking into account the atmospheric extinction, and comparing the results with their magnitudes quoted in a photometric catalogue.

*This goal could be met by running a copy of the final data reduction pipeline at Paranal on a subset of the data [see ISR040240 above].*

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040270** **The VISTA instrument software shall include graphical utilities for displaying VISTA quality control information**

**Need:** Requirement **Source: TS 5.5.4, 7.3.4**
**See also: SRD 7.5**

**Description:** The large number of detectors used by the VISTA instruments makes it essential that the data handling software provide facilities for displaying information about those detectors in a form easily digestible by the telescope operator. For example, a graphical display of the difference between today's dark current and yesterday's dark current for all the detectors will be easier to understand than a table of numbers. The displays should be designed so that the operator's attention is drawn to anything out of the ordinary. Such graphical information might include:

- Bad pixel maps for all the detectors colour coded so that bad pixels that don't appear in the current bad pixel calibration are easily spotted.

- A map showing trends in the detector dark current and detector sensitivity.
- A series of lights showing the health of various instrument components. If a light turns red the operator can click on it to find out what has gone wrong.

**How to test:** To be tested by reviewing the software design and by demonstration.

### 7.4.5 Data export

**ISR040280 The data processing software shall be able to coadd infrared exposures**

**Need:** Requirement **Source: TS 4.15.4.4, 5.5.1.4**
**See also: OCDD 2.7/5, 5.5.1, A.2.6**

**Description:** It is highly desirable for the data processing software at Paranal to be able to coadd all infrared exposures flagged as belonging to the same observation and the same dither position in temporary storage before writing the result to a permanent storage medium. (See ISR030100 and ISR040134).

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR040290 A copy of the raw data, observing log and data quality information shall be saved to transportable medium before the start of the next night**

**Need:** Requirement **Source: TS 6.1, 5.5.4**
**See also: OCDD 4.1.1/2, 4.2.1/1**

**Description:** A copy of all the raw data, observing log and data quality information created during a night should be saved to transportable medium before the start of data taking for the following night. The transportable medium will be exported to Garching.

**How to test:** To be tested by demonstration.

**ISR040300 Two copies of the raw data, observing log and data quality information may be saved to transportable medium before the start of the next night**

**Need:** Goal **Source: OCDD 4.1.1/2, 4.2.1/1, FPRD 10.070, 10.080**

**Description:** It is a goal for two copies of the raw data, observing log and data quality information to be written to transportable medium, so separate copies of the medium can be exported to Garching and the UK at the same time. (The alternative is for the UK copy of VISTA data to be made at Garching).

**How to test:** To be tested by demonstration.

## *7.5 Software Standards and Maintainability*

**ISR050010 All VISTA software shall be sufficiently reliable so as not to make any significant contribution to the overall target of less than 5% non-scheduled down time**

**Need:** Requirement **Source: TS 7.2.1**
**See also: SRD 7.1/2**

**Description:** The entire VISTA system is required to be sufficiently reliable that non-scheduled down time is less than 5% of nights (i.e. the system must be 95% reliable). The software must be sufficiently reliable that software faults do not contribute significantly to this downtime. A combination of good practice and rigorous testing will be required.

**How to test:** To be tested by reviewing the software design, reviewing the software coding standards and by soak testing.

**ISR050020 VISTA software shall be able to cope with a missing or broken detector**

**Need:** Requirement **Source: TS 6.1.6**
**See also: SRD 7.5/5**

**Description:** The VISTA data handling software should not make assumptions about which detectors are present and working. If a detector is broken or missing the software should be able to use the data provided by the other detectors (i.e. it should be possible for an entire detector to consist of bad pixels).

**How to test:** To be tested by reviewing the software design and by testing with missing (or unplugged) detectors.

**ISR050030 VISTA software should be able to cope with a non-functioning filter identification device**

**Need:** Goal **Source: TS 6.1.6**
**See also: SRD 6 (survey speed)**

**Description:** . The VISTA instrument software should allow an observation to be made when the filter identification device cannot be read. In this case the

telescope operator will be responsible for identifying the filter. This will allow observing to continue the filter identification reader fails during the night or a filter is installed without a device. NOTE: It is important that the FITS header accurately reflects what has been observed, so the operator must be able to identify the filter.
(The same goal could be extended to any device that is non-essential but might fail during the night).

**How to test:** To be tested by reviewing the software design and by testing with a faulty filter.

**ISR050040 All VISTA software shall be written to ESO standards**

**Need:** Requirement **Source: TS 1.1, 3.1, 5, 5.4.5.1/2, 5.4.2.1**
**See also: [AD6], SRD 7.1/1**

**Description:** The software must be designed, coded and documented to ESO standards.

**How to test:** To be tested by reviewing the software design and coding standards.

**ISR050050 Existing ESO software shall be used or adapted wherever sensible**

**Need:** Requirement **Source: TS 5.4.2.1, 5.4.4.1, 5.5.1.1**
**See also: SRD 7.1/1, [AD6]**

**Description:** Existing ESO utilities should be used or adapted for VISTA wherever this is of a real benefit. Modifications to ESO utilities should be agreed with ESO. New utilities can be provided for VISTA when existing ESO utilities are not suitable.

**How to test:** To be tested by reviewing the software design.

**ISR050060 Maintenance ("engineering") software shall be provided to allow detailed checking of the instrument**

**Need:** Requirement **Source: TS 7.3.4**
**See also: [AD6]**

**Description:** Maintenance software should provide a detailed display of mechanism positions, switch positions and any monitored values such as temperatures. Engineering software should allow direct low-level control of the instrument mechanisms by a knowledgeable engineer. This is an ESO standard.

**How to test:** To be tested by reviewing the software design and demonstrating the maintenance software.

### ISR050070 Automated test procedures shall be provided for each instrument

**Need:** Requirement **Source: TS 7.3.4**

**Description:** Automated test procedures should be provided to check-out all the testable instrument mechanisms in a repeatable way, with minimal input from an engineer. The test results should be saved to a log file. The general requirement is that there be set of procedures that can blanket-test all the instrument mechanisms and pick up any problems with little-used mechanisms that might otherwise be missed. Each test procedure should be designed to take no longer than about one hour to execute, and should preferably be much faster than this. (Individual test procedures can be strung together to make automated test sequences or soak tests longer than this if needed). The initial assumptions made by each test procedure should be clearly stated so an engineer can verify them and confirm that the procedure can safely begin. An example of a test procedure might be:

- For those devices with a home switch, move the device and attempt to detect that switch.
- Attempt to move mechanisms with a limited range of travel into their limits and confirm the limit switches work.
- Check the operation of any brakes.
- Confirm the readings from any encoders.
- Move filter wheel to each position and check operation of in-position sensor.
- Attempt to read the identification device for each filter.
- Drive all the devices in each of their possible operating modes.
- Check that any signals read from the electronics (e.g. temperatures) are reading sensible values.

The exact nature of the tests will depend on the information available to the software. The test procedures could be used, for example, to test the instrument after a major rebuild, or to test the software (on the same hardware) after a new version has been released.

**How to test:** To be tested by reviewing the software design and demonstrating the test procedures.

### ISR050080 Instrument systems shall have a simple self-test facility

**Need:** Requirement **Source: TS 7.3.4**
**See also: OCDD 4.1.2/6, 4.2.2/6, [AD6]**

**Description:** There needs to be a check at the beginning of each night to ensure that the VISTA system is ready to begin night time operations [ISR010070 on page 29]. To do this the VISTA instruments need a simple self-test facility. This facility could take the form of a "test" command executed each night. Unlike the automated test procedures described in the previous requirement, this self-test should complete quickly — within a few seconds. As an example, in response to a self-test an instrument could:

- Ping its subsystems and make sure they are responding.
- Check memory access.
- Check all devices are present on the LCU bus and have connected to their device drivers.
- Check there are no unusual readings from TTL signals or analogue to digital converters (e.g. no interlocks, no garbage temperature readings).
- Check any instrument setup or calibration information (if any) has been successfully read.

**How to test:** To be tested by reviewing the software design, by demonstrating the test procedures and by inducing faults.

### 7.5.1 Common Maintenance Software

**ISR050090 Maintenance software shall be provided to calibrate the rotator centring on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.16**

**Description:** A maintenance procedure should be provided to measure the location of the rotator centre in the focal plane. This can be done by making a science exposure with the rotator moving, so the stars trail into arcs around the rotator centre.
*Fulfilling this requirement may just be a matter of displaying the images and making available a data reduction utility, such as IRAF.*
The procedure will typically be repeated after each camera change, or may be a one-off commissioning procedure.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050100 Maintenance software shall be provided to measure the detector pixel locations on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.5, 6.2.11**

**Description:** Maintenance software should be provided to map the positions and orientations of all the visible and infrared detector chips and hence the determine the mapping of each pixel onto the x,y focal plane. This could be done by observing a field of stars with different telescope offsets.
The procedure will typically be repeated monthly (or once for each thermal cycle of the visible or infrared camera)

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050110 Maintenance software shall be provided to measure the detector cross talk on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.7, 6.2.5**

**Description:** Maintenance software should be provided to calculate the detector cross talk from, for example: for the visible camera a series of dome flats taken through a pinhole mask filter or an observation of a bright star through a neutral density filter; or for the infrared camera observations of bright stars through a narrow band or neutral density filter. Measurements should be repeated with the point source falling at different detector locations and the relative brightness of any "ghost" images at matching pixel locations measured.
The procedure will typically be repeated annually (or perhaps after each camera change?)

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050120 Maintenance software shall be provided to check for electrical interference with detector readouts on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.9, 6.2.6**

**Description:** A maintenance procedure should be provided to check for electrical interference between telescope and instrument mechanisms and the visible or infrared detector readout (e.g. check for interference while slewing the telescope, moving the dome or reconfiguring the instrument). For the visible camera a series of ~10 bias or dark frames could be taken with nothing moving and with a selection of different mechanisms moving. For the infrared camera a series of dark frames could be taken with nothing moving and with a selection of different mechanisms moving. The mean values and RMS noise can be compared to detect any interference.

The procedure will typically be repeated after each camera change.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050124 Maintenance software shall be provided to check for bad pixels on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: SRD 7.5, OCDD 6.1.3**

**Description:** Maintenance software should be provided to examine a sample of the exposures (e.g. the dome flats) and determine the location of any bad pixels on each detector. The result should be saved as a bad pixel mask.
The procedure will typically be repeated after each camera change.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050126 Maintenance software shall be provided to determine the detector dark current on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: SRD 7.5**

**Description:** Maintenance software should be provided to determine the detector dark current from a set of dark frames.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050130 Maintenance software shall be provided to calibrate the amplifier linearity on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.10, 6.2.7**

**Description:** A maintenance procedure should be provided to examine the linearity of the conversion from detected electrons to output ADUs (visible) or detected photons to counts (infrared) in each detector. This can be done by taking a series of dome flats (with a single science filter) in a non-ordered series of exposure times (e.g. 60, 5, 30, 10, 40 seconds etc.). The longest exposure time should be arranged to be 100% saturated. Plotting ADUs or counts vs exposure time will measure the detector linearities. For accuracy, these calibrations could be fitted with a polynomial.

The procedure will typically be repeated after each camera change.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050140 Maintenance software shall be provided to carry out a light leak test on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.13, 6.2.8**

**Description:** A maintenance procedure should be provided to check for light leaks. This can be done by comparing long exposures taken with the shutter closed or blocking filter installed (visible), or with the cold blocking filter installed (infrared), with and without the dome lights on. A simple subtraction of the exposures may be sufficient to detect any light leaks.
*Fulfilling this requirement may just be a matter of making available a data reduction utility, such as IRAF.*
The procedure will typically be repeated after each camera change.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050150 Maintenance software shall be provided to check for ghost images on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.14, 6.2.9**

**Description:** A maintenance procedure should be provided to check for ghost images. This can be done by taking a series of exposures containing a bright star moved to different offsets. The ghost images can be distinguished from real stars because they will move in different directions. A map of the locations of the most series ghost images can be made.
*Fulfilling this requirement may just be a matter of displaying the images and making available a data reduction utility, such as IRAF.*
The procedure will typically be repeated annually.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050160 Maintenance software shall be provided to check for remnants on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.15, 6.2.10**

**Description:** A maintenance procedure should be provided to check for memory effects after illumination by bright objects. This can be done by making an over-exposed exposure on a bright source followed by a sequence of frames with the shutter closed (visible) or cold blocking filter installed (infrared).
*Fulfilling this requirement may just be a matter of displaying the images and making available a data reduction utility, such as IRAF.*
The procedure will typically be repeated annually for the visible camera and monthly for the infrared camera.

**How to test:** To be tested by reviewing the software design and by demonstration.

### 7.5.2 Visible Camera Specific Maintenance Software

**ISR050170 Maintenance software shall be provided to measure the visible camera amplifier gain on demand**

**Need:** Requirement — **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.8**

**Description:** Maintenance software should be provided to calculate the amplifier gain from a series of dome flats taken at varying exposure times (e.g. 10, 30 and 100 seconds). An example procedure would be:
- Scale observations to the same mean to remove lamp variations.
- Take the difference between the observations.
- Determine the gain from a plot of RMS vs mean counts.

The procedure will typically be repeated quarterly.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050180 Maintenance software shall be provided to calibrate the visible camera shutter linearity on demand**

**Need:** Requirement — **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.11**

**Description:** A maintenance procedure should be provided to check the linearity of the shutter timing, to ensure that the reported exposure time scales linearly with the actual exposure time. One way to do this would be to compare a 60 second exposure made with one shutter open/close operation with an exposure made of 30 shutter open/close operations of 2 seconds each

(assuming the dark current is insignificant compared with the signal being detected).
The procedure will typically be repeated after each camera change.

NOTE: This requirement assumes the visible camera has the ability to make one exposure with multiple shutter operations (see ISR030035).

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR050190 Maintenance software shall be provided to calibrate the visible camera shutter repeatability on demand**

**Need:** Requirement **Source: TS 6.1.3, 7.3.5**
**See also: OCDD 6.1.12**

**Description:** A maintenance procedure should be provided to check the repeatability of the shutter timing. This could be done by taking a sequence of dome flats with exactly the same exposure time and looking for random variations in the mean signal as a function of reported shutter open time.
The procedure will typically be repeated after each camera change.

**How to test:** To be tested by reviewing the software design and by demonstration.

### 7.5.3 Infrared Camera Specific Maintenance Software

*There are no infrared camera specific maintenance requirements.*

## *7.6 Resource Requirements*

**ISR060010 The software shall be compliant with ESO hardware.**

**Need:** Requirement **Source: TS 3.1, 5.4.1, 5.4.5**
**See also: [AD6]**

**Description:** The VISTA site will use either standard ESO hardware or hardware agreed by ESO, as described in [RD4]. The VISTA instrument software must be compatible with that hardware.

**How to test:** To be tested by reviewing the software design.

**ISR060020 The software shall run using operating systems compliant with ESO.**

**Need:** Requirement **Source: TS 3.1, 5.4.2, 5.4.5**

**See also: [AD6]**

**Description:** The VISTA computers will use either standard ESO operating systems or operating systems agreed by ESO, as described in [RD4]. The VISTA instrument software must be compatible with these operating systems.

**How to test:** To be tested by reviewing the software design.

## *7.7 Documentation Requirements*

**ISR070010 All external system interfaces shall be specified and shall comply with ESO requirements.**

**Need:** Requirement **Source: [NEW]**
**See also: TS 5.4.5.2**

**Description:** All the external interfaces between the VISTA instrument software and other systems need to be specified and agreed. In some cases interfaces have already been defined as part of the ESO standard (e.g. specification of an observing block) and what is needed here is additional information specific to VISTA (e.g. definition of a VISTA observing block). The following system interfaces need to be specified (section 3.2 on page 12):

- VISTA instrument software to Instrument Builder (information provided by the instrument builder);
- VISTA instrument software to Observation Planning System (system description and observation requests);
- VISTA instrument software to Optical Sensing Hardware (Optical sensing commands and responses) *(not an external interface if the instrument software and optical sensing hardware are provided by the same vendor)*;
- VISTA instrument software to Telescope Control System (TCS commands and responses);
- VISTA instrument software to Instrument Hardware (Camera Control Signals) *(not an external interface if the instrument software and instrument hardware are provided by the same vendor)*;
- VISTA instrument software to Detector Control System (DCS commands and responses);
- VISTA instrument software to Telescope Operator (TO commands, status information and quality control information);
- VISTA instrument software to Off-site Data Export (data headers and data, information logged).

**How to test:** To be tested by reviewing the documents.

# 8 Guiding, Focus and Wavefront Sensing Requirements

VISTA's instrument systems, rather than the TCS, will control the subsystems that generate guiding corrections, focus corrections and wavefront corrections. Although these subsystems may be developed separately to the instrument software, the instrument software will need to accommodate them.. Depending on the final work package partitioning some of the following may be part of the instrument software packages and some part of the optical sensing packages. The requirements below assume that different sensors are used for guiding, focus control and wavefront sensing, but the final design may combine some of these functions.

## *8.1 Guiding and Focus Control*

**ISR100010 Enable/disable the generation of guide and focus control demands**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7**

**Description:** The instrument software shall enable/disable the generation of guide and focus demands.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR100020 Guide and focus signals shall be sent to the telescope software**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7**

**Description:** Guide signals, i.e. errors in two dimensions, shall be sent to the telescope software at a rate sufficient to meet the performance requirements.

**How to test:** To be tested by measuring the guide signal rate.

**ISR100030 Configuration of guide and focus mechanisms**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7**

**Description:** The software shall configure filters etc. to match as closely as possible the requirements specified in the observation request.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR100040 Parameters for guide and focus stars sent to guide subsystem**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7**

**Description:** The observation request may specify stars to be used for guiding and focus control. The instrument software shall send to the optical sensing subsystem all information necessary to allow guide and focus demands to be generated. Depending on the design chosen, this information may include:
- area of interest on CCDs
- position within area of interest corresponding to zero guide error, taking into account filters in the science and guide light paths
- rate at which to generate demands

These parameters shall be updated as frequently as necessary to meet the performance requirements, e.g. to accommodate non-sidereal tracking and differential refraction.

**How to test:** To be tested by reviewing the software design and by demonstration.

### ISR100050 Automatic selection of guide and focus control stars

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The system shall be able to select automatically suitable stars for guiding and focus control. The operator shall be able to override the automatic selection.

**How to test:** To be tested by reviewing the software design and by demonstration.

### ISR100060 Preselected guide and focus control stars

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The system shall accept guide and focus control stars as specified in the observation request; in this case the operator can decide whether to use the specified stars or specify others.

**How to test:** To be tested by reviewing the software design and by demonstration.

### ISR100070 Manual selection of guide and focus control stars

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The operator shall be able to specify stars from on-line catalogues or by inspection of the displayed guide fields.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR100080 Details of selected guide and focus control stars shall be logged**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1.5**

**Description:** The following details of selected guide and focus control stars shall be logged:
- Position (RA, Dec and equinox)
- Time stamp
- Catalogue name (if available)
- Catalogue magnitude (if available)
- Filter of catalogued magnitude, chosen to be closest to that used (if available)

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR100090 Logging of focus control data**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1.5**

**Description:** The following data shall be logged at TBD Hz for each focus control star:
- focus demand
- brightness of image (in ADU)
- star's catalogued magnitude (if available)
- time stamp
- filter
- update rate

**How to test:** To be tested by reviewing the software design, by demonstration and by measuring the logging rate.

**ISR100100 Logging of guide data**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1.5**

**Description:** The following data shall be logged at TBD Hz for each guide star:
- guide demand
- FWHM of guide image
- ellipticity
- position axis of image's major axis

- brightness of image (in ADU)
- time stamp
- star's catalogued magnitude (if available)
- filter
- update rate

**How to test:** To be tested by reviewing the software design, by demonstration and by measuring the logging rate.

**ISR100110 Loss of lock**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 7.3.4**

**Description:** A warning shall be generated if guide or focus control lock is lost when enabled. Loss and repossession of lock shall be logged.

**How to test:** To be tested by reviewing the software design and by inducing a loss of lock, e.g. by blocking the guide star beam.

**ISR100120 Guiding and focus control status display**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 5.5.4**

**Description:** The following guide information shall be made available in a real time display:
- guide fields, displayed at 1 Hz TBD
- enabled/disabled indicators
- loop closed indicators
- data as logged with trend plots

**How to test:** To be tested by reviewing the software design, by demonstration and by measuring the display update rate.

## *8.2 Wavefront Sensing*

**ISR110010 Automatic selection of WFS stars**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The system shall be able to select automatically suitable stars for wavefront sensing. The operator shall be able to override the automatic selection.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR110020 Preselected WFS stars**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The system shall accept WFS stars as specified in the observation request; in this case the operator can decide whether to use the specified stars or specify others.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR110030 Manual selection of WFS stars**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1**

**Description:** The operator shall be able to specify stars from on-line catalogues or by inspection of the displayed guide fields.

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR110040 Measurement of wavefront errors**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 5.5.4**

**Description:** The instrument software shall support the measurement of wavefront errors by (depending on final design):
- determine if a wavefront measurement is required, e.g. by explicit demand or the elapsed time since the last measurement was performed
- offset the telescope to the specified star
- lock the guiding and focus (TBC)
- configure mechanisms, e.g. colour and neutral density filters
- make a measurement
- analyse the image to determine the wavefront error
- pass the wavefront error to the telescope control system
- log the data
- repeat for other wavefront stars if necessary

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR110050 Storage of wavefront images**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 5.5.1**

**Description:** All images used for wavefront analysis shall be stored as specified for science images.

**How to test:** To be tested by reviewing the software design.

**ISR110060 Logging of wavefront errors**

**Need:** Requirement **Source: TS 5.2.8, 5.3.7, 6.1.5**

**Description:** All wavefront errors passed to the telescope software shall be logged including

- zernike coefficients (or equivalent)
- time stamp
- ID of image(s) used to calculate wavefront
- filter used
- exposure time

**How to test:** To be tested by reviewing the software design and by demonstration.

**ISR110070 Wavefront status display**

**Need:** Requirement **Source: TS TS 5.2.8, 5.3.7, 5.5.4**

**Description:** The following guide information shall be made available in a real time display:

- wavefront image after acquisition
- FWHM of Shack Hartman spots (if applicable)
- measured wavefront coefficients
- details of star used, e.g. coordinates, catalogue name, type, magnitude
- measurement parameters, e.g. exposure time, filter

**How to test:** To be tested by reviewing the software design, by demonstration and by measuring the display update rate.

# 9 Appendix — Relationship to ESO-VLT Software Architecture

## *9.1 ESO Architecture Applied to VISTA*

If ESO-VLT software components are to be reused, the ESO-VLT architecture imposes a structure on the software looking something like this (see TS 5.4 and [RD1]).

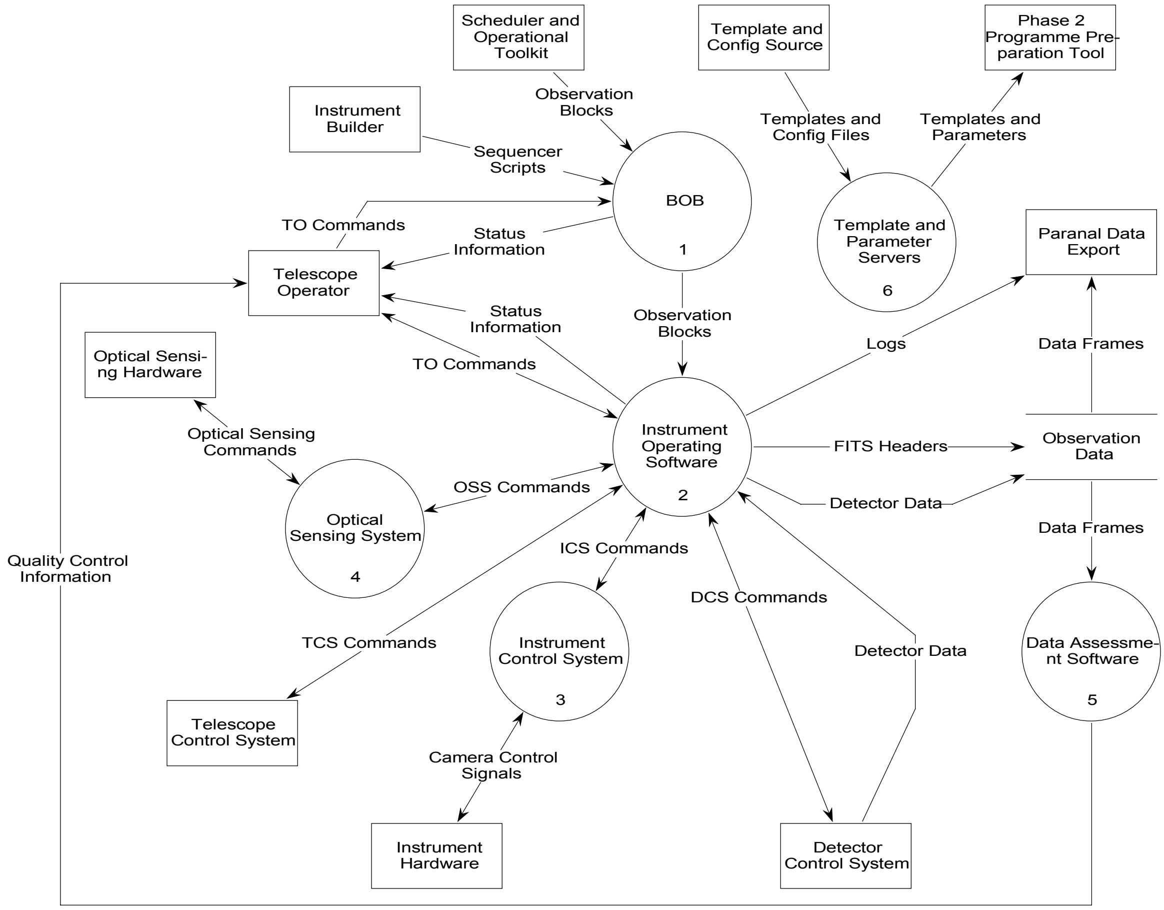


**Figure 5 Breakdown of the VISTA instrument software with ESO architecture**

In the ESO-VLT model each instrument control system receives an "Observation Block" (OB) which describes an observation. The observation blocks are created by a "Phase 2 Programme Preparation Tool" which uses templates and configuration files supplied by the observatory. These observation blocks are scheduled and sent to the instrument control system by a "Scheduler" and "Operational Toolkit". A "Broker for Observation Blocks" process (BOB, which is supplied by ESO) interprets the observation blocks and, with the aid of sequencer scripts provided by the instrument builder, issues instrument commands.

The instrument commands are interpreted by instrument operating software which fans out commands to the telescope control system (TCS), instrument control system (ICS) and detector control system (DCS, which may also be supplied by ESO). The instrument operating software also commands an "Optical Sensing System" which is responsible for controlling and interpreting the data from wavefront sensors.

In the ESO-VLT model detector data are written to an observation data store, and these data are interpreted by on-line and off-line data assessment processes which generate quality control information. The VISTA data are also archived off site by a data export system outside the scope of this document.

Note that any architectural diagrams are presented here only as an aid to defining the system boundaries and visualising the context of this software in relation to the rest of the ESO-VLT system. They are not meant as a software design. A complete and more accurate description of the VISTA software architecture is given in [RD1].

## *9.2 Overview of Work*

This section shows how the functions described in earlier sections (Planning of Observations, Scheduling of Observations, Executing Observations, Generation of Data Products, Generation of End-of-Night Reports, Final Data Processing) map onto the ESO-VLT software architecture, and indicate what kind of VISTA-specific software work is likely to be needed.

| VISTA Function | ESO-VLT Components | Work Required |
|---|---|---|
| Planning Observations | P2PP | Configure & Customise |
| Scheduling Observations | Scheduler | Configure |
| | Broker for Observation Blocks | Configure |
| Executing Observations | Observation Software | Implement |
| | Telescope Control System | ? |
| | Detector Controller | Configure ESO controller? Customise if needed? |
| | Instrument Controller | Implement |
| | Real-Time Display | Configure |
| Generate Data Products | Generated by subsystems | |
| Generate End-of-Night Reports | Local Pipeline | Provide C library |
| Final Data Processing | Garching Processing System | TBD |

## *9.3 P2PP - Phase 2 Programme Preparation Tool*

The minimum work required will involve providing configuration information describing the possible instrument setup choices (e.g. list of available filters). It might be necessary to add Java classes to describe features of the VISTA telescope and instruments (this is the way the various versions of the Gemini-originated "Observing Tool" used by Gemini, UKIRT and JCMT have descriptions of new instruments installed).

P2PP does not provide tools for repetitive observation requests, and this is an area where enhancement might be important. It would be very useful for VISTA if an entire survey could be generated with P2PP as a single observing programme.

## *9.4 Scheduler*

ESO plan to use an automatic scheduling tool being developed at NASA-Goddard. Configuration information will have to be provided to enable the tool to make scheduling decisions.

## *9.5 Broker for Observing Blocks*

This is an ESO tool which accepts the scheduled operation and splits it up into requests for single observations, which are passed one at a time to the observation software. It is likely some configuration information will need to be provided here, depending on how closely VISTA observing modes relate to ESO "templates".

## *9.6 Observation Software*

This has to be implemented to ESO standards. It is responsible for commanding the Telescope Control System, the Detector Controller and the Instrument Controller in such a way that the requested observing mode is executed. An explicit requirement from [AD1] means that, for efficiency reasons, the Observation Software must be able to drive the other systems in parallel.

## *9.7 Telescope Control System*

This is outside the scope of the Instrument System. It is expected to be the ESO Telescope control system, and it is currently unknown what VISTA-specific work will be required in this area. The most likely work will concern the autoguider. The section of this document which deals with quality control has implications for the specification of the autoguider.

## *9.8 Detector Controller*

The plan is to use ESO hardware and software.

## *9.9 Instrument Controller*

This has to be implemented to ESO standards, as described in this document.

### *9.10 Real-Time Display*

The ESO display software will probably be used for this. Some configuration will be required. Arrangements will have to be made to send data to it.

### *9.11 Local Pipeline*

A library of data processing routines written in C has to be delivered to ESO, who will incorporate it into their pipeline system.

### *9.12 Data Products and FITS Header Items*

The Data Products have to be exported to the ESO archive. For this, there has to be conformation with the ESO Data Interface Control Document [AD4] which specifies things such as how data frames from array mosaics map onto FITS files. Mandatory normal FITS headers plus ESO hierarchical FITS headers are specified. It may be necessary to convert raw data in ESO format into a standard UK-format to allow the UK data processing pipeline to handle the data.

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