Fast Tip-Tilt/Narrow-field Acquisition System: Top-level Requirements

INT-403-ENG-0003 rev 0.3

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Change Record

Revision	Date	Authors	Changes
0.1	2005-09-16	JSY, CAH	Previous incomplete document
0.2	2006-09-29	JSY	Completely new draft
0.3	2006-10-02	JSY, CAH	Revised based on CAH comments

Objective

To specify the top-level requirements for the MROI Fast Tip-Tilt/Narrow-field Acquisition systems.

Scope

This document aims to specify the top-level requirements for the MROI Fast Tip-Tilt/Narrow-field Acquisition (FTT/NA) systems, in particular:

- Functional requirements: *what* the system must do
- Performance requirements: *how well*, and *under what conditions* the system must perform its functions
- Identification of interfaces
- Relationship to Work Breakdown Structure (WBS) (important for systems that cross WBS boundaries)

Design and Implementation Process

This document is intended to be the first step in the design and implementation process outlined below. It does not attempt to provide sufficient detail to identify suitable components (e.g. CCD cameras) — this will be possible after the conceptual (for major components) or detailed design phases.

1. Top-level requirements definition (this document)
2. Conceptual design, including:
   (a) Critical hardware issues
   (b) Critical software issues
3. Survey of Commercial Off-The-Shelf (COTS) hardware for major components
4. Detailed design
5. Procurement
6. Software implementation
7. Integration and test

Referenced Documents

The following documents are incorporated by reference:

INT-402-MIS-0004 "Acquisition - 1", Nathalie Thureau and Chris Haniff (preliminary document)

INT-402-MIS-0008 "Acquisition - 2", Nathalie Thureau, John Baldwin and Chris Haniff (preliminary document)

INT-403-TSP-0003 rev 1.1 "Technical Requirements: Unit Telescopes for the MRO Interferometer"

INT-403-TSP-0002 rev 8 "Requirements for the Unit Telescope Optics for the MRO Interferometer"

INT-404-TSP-0003 rev ? "Requirements for the Enclosures for the MRO Interferometer"

Acronyms used in this document

API Applications Programming Interface

BCA Beam Combining Area

BCF Beam Combining Facility

CCD Charge-Coupled Device

COTS Commercial Off-The-Shelf

FTT Fast Tip-Tilt

GUI Graphical User Interface

ICS Interferomet(er)(ric?) Control System

NA Narrow-field Acquisition

UT Unit Telescope

WBS Work Breakdown Structure

1 Assumptions

This document is predicated on the following decisions about the conceptual design of MROI and the FTT/NA system. These decisions have previously been made by the system architects, and are justified in the referenced memos.

- Use of the same camera for narrow-field (routine) acquisition and tip-tilt sensing (INT-402-MIS-0004).
- One such camera installed at each of the six Unit Telescopes (INT-402-MIS-0004).
- Splitting of starlight by colour between tip-tilt sensing, fringe tracking, and interferometric science (INT-402-MIS-0008).
- For reasons of cost, the FTT/NA system shall use silicon-based detectors (which are sensitive to wavelengths in the range 350–1000 nm).

2 System Components

A block diagram of the FTT/NA system is shown in Figure 1. An outline description of each component in the figure follows. This breakdown includes all system components, but is only detailed at a level sufficient for the reader to understand this document.

The following parts of the FTT/NA system include optical components that are mounted on the UT "Nasmyth" optical table (see INT-403-TSP-0003):

- Dichroic: reflects the colours of light to be fed to the FTT/NA CCD detector while transmitting the colours used for fringe tracking and interferometric science. May have capability to switch between different dichroics (needed for visible science, i.e. MROI Phase 2)
- Focusing optic: forms an image of the target object on the CCD detector
- CCD detector system, comprising:
  - CCD head
  - Cooling system
  - Readout electronics
  - Power supply

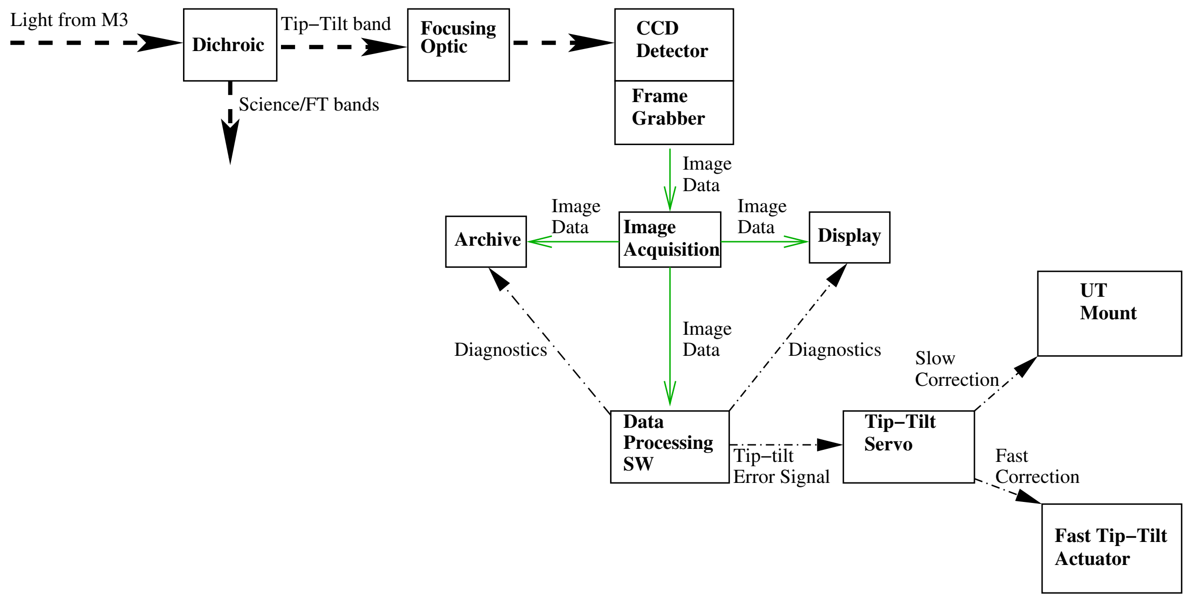

Figure 1: Block diagram of the FTT/NA system.

- Alignment optics: any further components (e.g. alignment targets, retroreflectors) needed to:
  - Align the FTT/NA optical axis to the UT exit beam
  - Align internal degrees of freedom of the FTT/NA system

The following include some parts that are specific to the FTT/NA system, and some that are common to other MROI functionality:

- Image acquisition hardware/software:
  - Frame grabber hardware (if required)
  - Software for real-time data transmission over the network
  - Software for real-time/a posteriori image display
  - Hardware/software for image archiving
- Real-time data processing software (tip-tilt and acquisition):
  - Image clean-up (remove artifacts, flat-field etc.) — requires previously-recorded dark and flatfield frames
  - Find stellar images
  - Centroid, to obtain tip-tilt error signal
  - Tip-Tilt Servo implementation (see Sec. A.4 of INT-403-TSP-0003)

The following components, to be delivered as part of the UT contract (see INT-403-TSP-0003), are involved in closing the acquisition and tip-tilt loops:

- Unit Telescope Mount, with interface for mount offset commands
- Fast Tip-Tilt Actuator (FTTA)

Q1. Which, if any, of the software components mentioned above do we consider to be part of the ICS?

Q2. Is it useful to define the FTT/NA *sensor* as everything except the last 3 bullets?

3 Requirements: Operating Modes

The FTT/NA system shall implement the following modes, and be able to switch between any two modes within 5 seconds (goal 1 second). The functional requirements for each mode are detailed in Sec. 4.

3.1 Fast Tip-Tilt Mode

The system captures frames continuously at a (variable) fast rate, feeding back high-frequency tip-tilt corrections to the FTTA, and low-frequency pointing corrections to the UT mount.

In this mode, the system shall provide estimates of the spatial seeing at a rate of at least 0.1 Hz.

3.2 Acquisition Mode

The system captures frames continuously at $\sim$1 Hz, feeding back pointing corrections to the UT mount.

In this mode, the system shall provide rough estimates of the spatial seeing, for use in choosing initial operational (e.g. bandwidth) and calibration (e.g. centroid calibration) parameters for the fast tip-tilt mode.

3.3 Acquisition Check Mode

The system captures then displays a single long-exposure (up to 10 sec) frame, to check what objects are in the field.

3.4 Dark Frame Mode

The system captures and archives a specified number of dark frames, using a detector readout scheme (subframing, integration time etc.) identical to that employed for a specified mode listed above.

3.5 Flatfield Mode

The system captures and archives a specified number of flatfield frames, with a user-specified integration time (up to 100sec).

Note: subframe sizes and frame rates for the above modes will be specified as part of the conceptual design.

4 Functional Requirements

4.1 Spectral Bandwidth

The FTT/NA sensor shall use light from all or part of the wavelength range 350–1000 nm; the astronomical J, H, and K bands being transmitted to the Beam Combining Facility (BCF).

A future upgrade to visible science will require that the entire 600–1000 nm band also be transmitted to the BCF.

In the subsections that follow, we specify functional requirements specific to certain of the operational modes defined in Sec. 3.

4.2 Fast Tip-tilt Mode

The field-of-view of each captured frame in Fast Tip-Tilt Mode shall be at least 2 arcsec $\times$ 2 arcscec ($\pm\sigma_U$ if r_0 =5 cm).

The system shall support closed-loop 3dB bandwidths in the range 10–50 Hz (INT-403-TSP-0003).

The system shall support closed-loop 3dB bandwidths in the range 1–10 Hz, for near-infrared science observations of heavily-reddened objects.

Q3. Is it sensible to drive the FTTA at these below-specification bandwidths?

4.2.1 Off-axis tip-tilt sensing

It shall be possible to select an off-axis object up to 30 arcsec from the science target as the reference for the fast tip-tilt mode.

4.3 Acquisition Mode

The field-of-view of each captured frame in Acquisition Mode shall be at least 80 arcsec $\times$ 80 arcsec ($\pm 2\sigma_P$), with a goal of 120 arcsec $\times$ 120 arcsec.

It shall be possible to integrate use of Acquisition Mode into the UT pointing and calibration sequence (INT-403-TSP-0003 Sec. 2.5).

4.4 User Interface

One or more Graphical User Interfaces (GUIs) shall be implemented, permitting:

- Control of all FTT/NA system functions, including diagnostic and commissioning functions
- Real-time and a posteriori display of captured frames
- Real-time and a posteriori display of FTT/NA system telemetry

Some or all of these functions may be provided by the central Interferometer Control System (ICS).

4.5 Diagnostic Functions

The FTT/NA system shall be able to archive detector frames captured in Fast Tip-Tilt Mode, Acquisition Mode, and Acquisition Check Mode, for diagnostic purposes.

In addition, sufficient telemetry shall be recorded to allow likely problems with the FTT/NA system to be diagnosed.

4.6 Commissioning Functions

The FTT/NA system shall provide the following functions, for use in debugging other aspects of MROI:

Q4. Are there any commissioning requirements to list here?

Table 1: Environmental and seeing conditions under which performance requirements in Sec. 5 must be met. The conditions on the optic table are assumed to be identical to the ambient nighttime conditions. Unlike in INT-403-TSP-0003, we make no distinction between "optimal" and "reduced performance" observing environments.

Parameter	Range	Origin
Electronics Housing:		
Temperature	0 to +40°C	INT-404-TSP-0003, or specified by UT vendor?
Relative humidity	TBD	To be specified by UT vendor?
Optic Table:		
Temperature	-25 to +20°C	INT-403-TSP-0003
Relative humidity	5% to 95%	INT-403-TSP-0003
Seeing:		
Fried parameter r_0 at 500 nm	5 cm to 20 cm	
Mean wind speed of turbulent layers	up to 20 m/s	

5 Performance Requirements

Each FTT/NA system shall meet the performance requirements outlined in Secs. 5.2 through 5.6 below, given:

- The wavefront error delivered by the UT as specified in Sec. 5 of INT-403-TSP-0002.
- The photon throughput of the UT as inferred from the coating specifications in Sec. 6 of INT-403-TSP-0002.
- The response of the UT mount as specified in Sec. 2.6.3 of INT-403-TSP-0003.
- A FTTA that meets the range, resolution and bandwidth specifications in Sec. 4.4 of INT-403-TSP-0003.

5.1 Environment

The FTT/NA system shall meet the performance requirements outlined in Secs. 5.2 through 5.6 under the environmental and seeing conditions given in Table 1.

5.2 Degradation of science/fringe tracking beam

The FTT/NA dichroic(s) shall introduce no more than TBD nm rms wavefront error into the transmitted beam (value to be derived from the system error budget).

The FTT/NA dichroic(s) shall deliver an average throughput of 99% in the J, H and K astronomical bands (value to be made consistent with the system error budget).

For Phase 2 of MROI, the FTT/NA dichroic used for visible science shall also deliver an average throughput of 99% for wavelengths 600–1000 nm (value to be made consistent with the system error budget).

5.3 Limiting Magnitude

The limiting magnitude for Fast Tip-Tilt and Acquisition modes shall be $V = 16$ (when JHK light is being used for fringe tracking and science), for objects with $V - I$ colour bluer than TBD, under the full range of seeing conditions outlined in Table 1.

A brighter limiting magnitude shall apply when using 600–1000 nm light for science.

5.4 Fast Tip-Tilt Performance

The atmospheric tip-tilt shall be corrected sufficiently well that the measured fringe visibility at 1.65 μm is not degraded by more than 10% compared with the visibility expected for perfect tip-tilt correction. This requirement applies for targets brighter than the limiting magnitude in Sec. 5.3, under the full range of seeing conditions outlined in Table 1.

For off-axis tip-tilt sensing, a less stringent requirement derived by accounting for atmospheric anisoplanatism shall apply.

Any changes in the effective tip-tilt zero-point (referred to the optic tables in the Beam Combining Area (BCA)) since start-of-night calibration must be accommodated within the system error budget term for quasi-static tip-tilt errors (2% visibility loss overall at 1.65 μm wavelength).

Q5. Any other top-level performance requirements?

Note: performance requirements for the CCD camera will be derived as part of the conceptual design.

5.5 Power Dissipation and Consumption

Wherever possible, electronic components of the FTT/NA system that dissipate significant power shall be located in the UT electronics housing (see INT-404-TSP-0003).

The components of the FTT/NA system located on the UT optic table shall dissipate no more than 10 W (TBC) of power to the air underneath or within 30 cm of the beam path.

The FTT/NA system (excluding the UT mount and FTTA) shall consume no more than 100 W (TBC) total.

5.6 Lifetime and Maintenance Requirements

The system shall not require routine maintenance (defined to mean any procedure that requires personnel to enter the UT enclosure) at intervals of less than 6 months. Note that this requirement precludes the use of cryogenic cooling for the CCD camera.

The system shall be designed for a lifetime of 10 (TBC) years.

6 Interface Requirements

In this section we list the interfaces between the FTT/NA system and external MROI systems. The requirements for each interface will be defined at the conceptual and detailed design phases.

- Optical Interface to Unit Telescope (e.g. input beam size, location, orientation)
- Optical Interface with Alignment System
- Mechanical Interface to Unit Telescope (e.g. physical envelope, shock loads during transport)
- Interfaces to Utilities (power, cooling, network, timing signals)
- Controls Interface to Interferometer Control System
- Controls Interface to Fast Tip-tilt Actuator (specified by UT vendor)
- Controls Interface to Unit Telescope Mount (specified by UT vendor)

7 Upgrade Path

The system shall be designed to allow for a future upgrade to visible science (see requirements in Secs. 4.1 and 5.2), with as few components as possible being discarded.

In procuring components, a possible need to build four further (ideally identical) systems in future shall be borne in mind.