Southern African Large Telescope

Prime Focus Imaging Spectrograph

Preliminary Control System Design

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1 Introduction

This document describes the preliminary design of the Prime Focus Imaging Spectrograph (PFIS) Control System (PCS).

PFIS has 9 mechanisms, enumerated in Section 2. There is only one mechanism with a requirement for hard-real-time control, the shutter. This control has been assigned to the detector control computer, to assure proper synchronization with the array controller. The remaining mechanisms are standard linear and rotary motions with position encoding, indexing, and safety interlocks.

There are no interactions between mechanisms, other than health and safety interlocks.

There are two external control and data interfaces, one with the Detector Controller Subsystem and one with the Telescope Control System. The PFIS interacts with the Detector Controller Subsystem during an observation, for slit viewing, slit mask peakup, and science data collection. The PFIS interacts with the Telescope Control System for gross pointing, target acquisition, and during an observation for small time-critical pointing changes.

Note that although the Detector Controller Subsystem is part of the PFIS instrument as a whole, that subsystem is being developed separately by the South African Astronomical Observatory (SAAO), and is considered by this document to be separate from the PFIS control system. The interface between the PFIS control system and the Detector Controller system is governed by a project Interface Control Document, and the internal architecture of that subsystem is beyond the scope of this document.

2 Mechanism Requirements

This section lists the control requirements for each mechanism. In the preliminary design, we treat only the basic motion control functions and indicators. The issues of health and safety interlocks, soft and hard limits, and assignment of responsibility between software and hardware systems will be detailed in the critical design. The one design philosophy that we can stress here is that it will be impossible for the software to harm the hardware. The safety analysis and hardware implementation will ensure that the worst result of control errors will be limited to loss of observing time.

The attached spreadsheet outlines the control requirements of each mechanism. In the "Encoder" column, we use the following terms:

- Position, Angle: the output of an incremental encoder, expressed as an integer, read from a PCI data acquisition card.
- Index: an indication of a home or reference position, used to assign an absolute reference to an incremental encoder. Once an index is sensed, then physically meaningful values can be assigned to the incremental encoder readings. On startup, the actuator control modules will perform an initialization sequence that seeks the index marks. On a normal shutdown, the actuators will be left in a state that minimizes the initialization time.

- Limits: binary indications of important positions, such as end of travel, in/out, up/down, home, soft and hard limits. These limits are sensed by the actuator control modules and are used by the modules to prevent engaging the hardware interlocks, and are passed up the control hierarchy for higher level control and status display.

Mechanism	Operation	Actuator	Encoder	Travel	Power (W)	Time (s)	# Ops/Obs	Energy (J)
Slit Mask	In/Out	Stepper	Position	200 mm	12	20	1	240
			Index					
			Limits					
Slit Mask	Select	Stepper	Position	350 mm	12	30	1	360
			Index					
			Limits					
			Bar Code					
Wave Plate	In/Out	Pneumatic	Limits	170 mm	0.55	15	2	16.5
Wave Plate	Rotate 1	Stepper	Angle	90 deg	12	6	32	2304
			Index					
Wave Plate	Rotate 2	Stepper	Angle	90 deg	12	6	32	2304
			Index					
Shutter	Open/Close	Pneumatic	Limits		0.55	1	2	1.1
Focus	Linear	Stepper	Position	3 mm	15	1	1	15
			Limits					
			Index					
Etalon 1	In/Out	Pneumatic	Limits	300 mm	0.55	50	4	110
Etalon 2	In/Out	Pneumatic	Limits	300 mm	0.55	50	4	110
Grating	Select	Stepper	Position	92 mm	12	12	1	144
			Index					
			Limits					
Grating	In/Out	Pneumatic	Limits	265 mm	0.55	10	2	11
Grating	Rotate	Stepper	Angle	45 deg	12	3	2	72
			Index					
			Limits					
Beam Splitter	In/Out	Stepper	Angle	75 deg	12	3	2	72
			Index					
			Limits					
Filter	Select	Stepper	Position	154 mm	12	18	1	216
			Index					
			Limits					
Filter	In/Out	Stepper	Position	270 mm	12	25	2	600
			Index					
			Limits					
Articulation	Rotate	Stepper	Angle	90 deg	12	70	1	840
			Index					
			Limits					
			Steppers	11		Total Energy (J)		7415.6
			Pneumatics	4		Typ. Obs. (s)		3600
			Incr. Encoders	11		Avg. Pwr. (w)		2.1
			Index Marks	11				
			Limits	26				

2.1 Slit Mask Mechanism

The slit mask mechanism consists of a magazine of about 50 slit masks, each contained in a bar-coded invar frame. The frames are stacked in a magazine. The mask in use lies in the focal plane. The magazine cannot be moved to select masks, because that would result in moving the magazine through the focal plane, violating the instrument envelope. Instead, the masks are selected by having an elevator stage move along the magazine, select the desired mask, and then physically transport it to the focal plane and insert it into the beam.

2.2 Wave Plate Mechanism

The wave plate mechanism is a 2-state device, with the wave plate unit in the beam or an optically flat compensator in the beam. The wave plate unit consists of two independently rotating wave plates.

2.3 Shutter Mechanism

The shutter mechanism is a commercial solenoid-operated (Prontor) shutter. The solenoid generates heat when the shutter is open, so either the solenoid will be cooled by a glycol loop or the shutter will be modified to operate pneumatically. The control has been assigned to the detector controller computer, but the shutter state will be monitored by the PFIS control system.

2.4 Focus Mechanism

The focus mechanism is a high-precision linear slide.

2.5 Etalon Mechanism

Two etalon mechanisms will be mounted as mechanically separate units on the PFIS. Each of 4 states (both in, both out, or one of each) will be used when observing. The etalon mechanisms and housings are identical to each other. The etalons are used only in the unarticulated (imaging) position.

2.6 Grating Mechanism

The grating mechanism is arguably the most challenging one in PFIS. One of 6 gratings must be selected, inserted into the beam, then rotated to the desired angle with respect to the beam. The mechanism must be interlocked with the etalon control, to prevent simultaneous operation.

2.7 Polarizing Beam Splitter Mechanism

The polarizing beam splitter is a simple in/out mechanism. The optic is rotated in and out of the beam.

2.8 Filter Mechanism

The filter mechanism has an operational constraint similar to the slit mask mechanism, in that in cannot violate the detector end of the instrument envelope. It also uses a fixed magazine and an elevator stage.

2.9 Articulation Mechanism

The articulation mechanism moves the camera arm through a 90 degree motion. The unarticulated position is used for imaging modes, the articulated positions are used in spectrographic modes.

3 Mechanism Interlocks

The PFIS has 9 mechanisms, not all of which operate independently of each other. For example, the grating selection mechanism must never be operated with the camera arm articulated, and never with the etalons inserted into the beam. Table 1 presents a preliminary list of interlock requirements.

Mechanism or Actuator Motion	**Restriction**
Slit mask into/out of beam	Slit mask elevator in home position
Slit mask elevator up/down	Slit mask inserter in middle position
Slit mask get/put	Slit mask elevator aligned with mask bay
Etalon in/out	Camera unarticulated Grating out
Grating in/out	Camera unarticulated Etalons out Grating not rotated
Grating rotate	Etalons out Grating inserted
Filter in/out of beam	Filter elevator in home position
Filter elevator up/down	Filter inserter in middle position
Filter get/put	Filter elevator aligned with filter bay

4 Control System Design

The section presents the preliminary design of the PFIS control system.

4.1 Computer Hardware

The PFIS control system will be implemented on a standard PC-style computer. It will act as the PFIS mechanism controller, the interlocks manager, and the instrument configuration manager. The PC will be rack-mounted in the computer room, with keyboard and monitor in the operator's area.

An RS-232 serial line will run from the PFIS PC to the Queensgate etalon controllers in the Igloo. A special Queensgate cable will run from the Igloo, up through the cable wrap, through the PFIS connector face, and up to the etalon assemblies. The cable must run without any intermediate connectors.

A fiber link will connect the SAAO PC to the Leach array controller on the articulated camera arm in PFIS. This fiber will have no intermediate connections.

4.2 Operating System

We are targeting Linux as the operating system of choice, to achieve compatibility with other subsystems in the observatory. One issue at PDR time is that although National Instruments supports LabVIEW for Linux, it does not yet support any of their motion control products on Linux. Current Linux support is limited to their data acquisition products. Our fallback position is to operate under some version of Microsoft Windows, but carefully keeping the PFIS implementation OS-neutral, allowing a low-risk migration to Linux should National Instruments complete their support for Linux.

4.3 Electronics

We intend to use commercial off-the-shelf (COTS) components wherever possible. During the critical design period, we will determine to what extent any custom electronics are needed. We expect that this will be limited to signal conditioning circuits for mechanism sensors and encoders.

We plan to use National Instruments (NI) motion control and data acquisition hardware. We will host the control electronics in a PXI chassis mounted on the PFIS structure. PXI is a NI product that provides a PCI backplane remotely to a PC. The PXI chassis can be far (>> 100 m) from the control PC, and allows standard PCI control cards to be used remotely by the PC. The interconnect is a high bandwidth optical fiber.

PXI components meet the following specifications.

Specification	**Value/Range**
Operating Temperature	0 to +55 C
Storage Temperature	-20 to +70 C
Operating Humidity	10 to 90%, noncondensing
Storage Humidity	5 to 95%, noncondensing
Functional Shock	30 g peak, half-sine, 11 ms pulse
Random Vibration - Operating	5 to 500 Hz, 0.3 g (rms)

Random Vibration - Nonoperating	5 to 500 Hz, 2.4 g (rms)
Safety	EN 61010-1:1993
EMC/EMI	CE, C-Tick, and FCC Part 15
Electrical Emissions	EN 55011 Class A at 10 m FCC Part 15 Class A above 1 GHz
Electrical Immunity	EN 61326:1998, Table 1

We are baselining the following components.

Component	**Part Number**
8-slot 3UCard Chassis	1 x NI PXI-1000B
Optical fiber to PC	2 x NI MXI-3 (one needed at each end)
2-Port RS232 for Etalon Control	1 x NI PXI-8420 777736-02
Voltage/Temperature Digitizer	1 x NI 4351 777790-01
16-Channel General Purpose Switch	1 x NI 2565 777754-01
96-Channel Digital I/O Module	1 x NI PXI-6508 777598-01
4-axis Closed Loop Motion Controllers	3 x NI PXI-7324 777712-04

4.4 Software

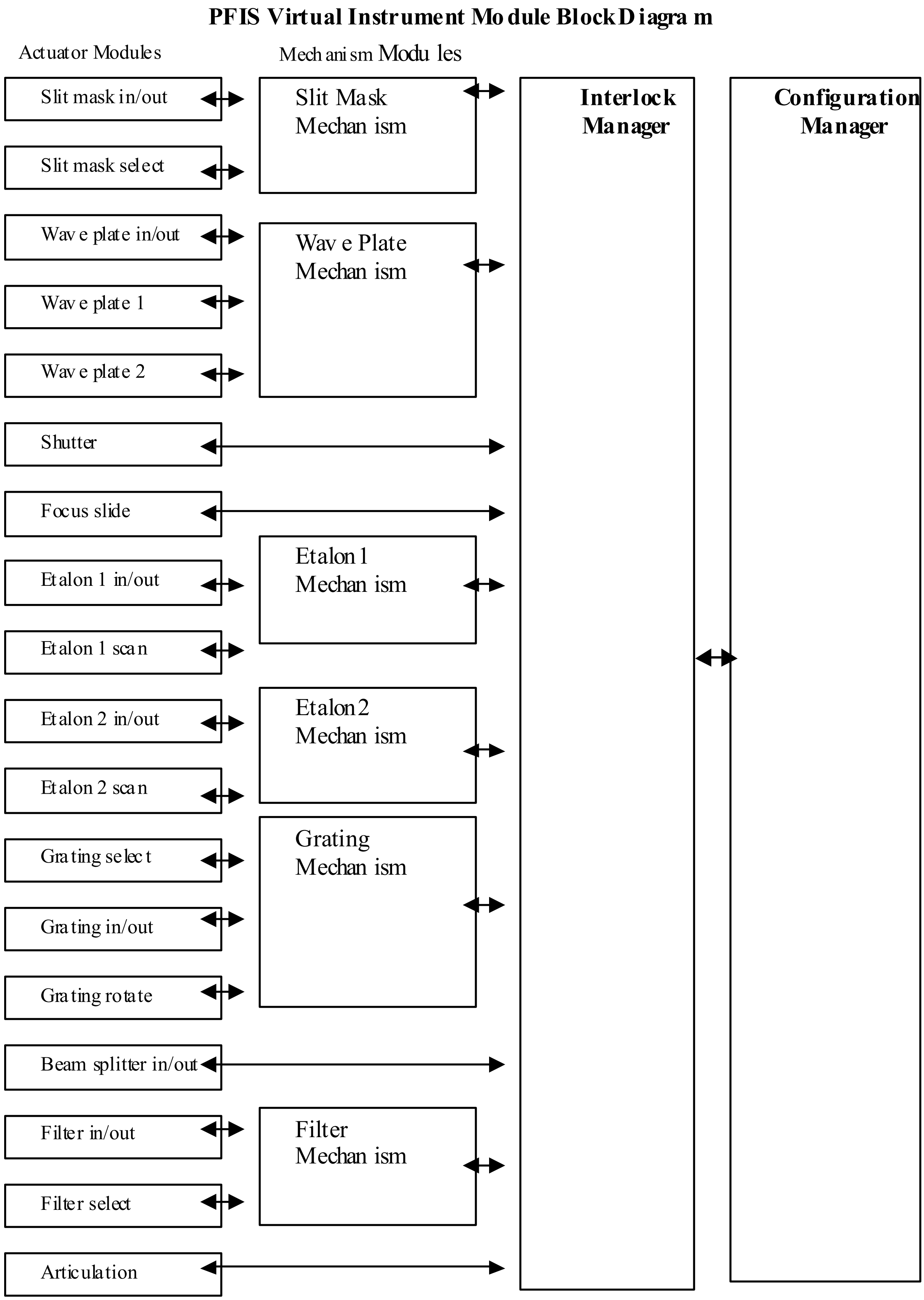
We are targeting the National Instruments LabVIEW product for the PFIS control system. LabVIEW will be commonly used in other SALT subsystems, and it is ideally suited for the kinds of motion control and data acquisition required by PFIS.

LabVIEW control systems use the concept of a Virtual Instrument (VI) for control and data processing. A VI has software inputs and outputs that represent all the electronic and data I/O in the real device. The programmer graphically interconnects a VI's I/O with other VIs and graphical user interface elements such as buttons, monitors, and alerts. It is modular and hierarchical, allowing VIs to become elements in higher-level VIs.

The PFIS control system will be designed in a modular fashion that will support bench testing of individual actuators and mechanisms, as well as operating the fully-integrated instrument.

Each VI will have its own user interface to support stand-alone operation and bench testing of individual actuators. These interfaces will be inherited by the VIs higher in the control hierarchy, and will be available (although probably hidden) at the top-level control module to allow a user to "drill down" through the module hierarchy when diagnosing a problem.

Figure 1 shows the PFIS software block diagram.


PFIS Virtual Instrument Module Block Diagram
Actuator Modules
Mechanism Modules
Slit mask in/out
Slit mask select
Wave plate in/out
Wave plate 1
Wave plate 2
Shutter
Focus slide
Etalon 1 in/out
Etalon 1 scan
Etalon 2 in/out
Etalon 2 scan
Grating select
Grating in/out
Grating rotate
Beam splitter in/out
Filter in/out
Filter select
Articulation
Slit Mask Mechanism
Wave Plate Mechanism
Etalon 1 Mechanism
Etalon 2 Mechanism
Grating Mechanism
Filter Mechanism
Interlock Manager
Configuration Manager

4.4.1 Actuator VIs

Each actuator (motor, pneumatic cylinder) in PFIS will be represented by an actuator-level VI, which manages the operation, health, and safety of the actuator. It will manage limit sensing, and will prevent any actuator-level operations that affect the health and safety of the actuator.

Each actuator VI will also incorporate a simulation mode, described below.

4.4.2 Mechanism VIs

Each mechanism will be represented by a mechanism-level VI. This distinction is important for the multi-actuator mechanisms such as the slit mask, waveplate, grating, and filter mechanisms. The mechanism VI will integrate the operations of the actuators to achieve the proper functioning of the mechanism. For a mechanism with only a single actuator, the actuator-level VI will also act as the mechanism-level VI.

The mechanism VI will implement the software interlocks for its actuators. A mechanism VI will not allow any combinations of actuator control that is defined to be illegal, such as inserting a slit mask into the beam when the elevator is not at the ground level.

4.4.3 Interlock VI

The Interlock VI manages the mechanisms as an integrated set. For example, the etalons and gratings are manipulated only when the camera arm is unarticulated, and the grating mechanism is never operated with the etalons in place. The relationships between mechanisms are encoded at the level of the Interlock VI.

It is the job of the Interlock layer to avoid conflicts between mechanisms. Its job is to avoid having any of the hardware interlocks having to be invoked. Note that it is not the job to advise on what configurations may be meaningful, rather it should only prevent the ones that are harmful. This is an important distinction for instrument test and configuration. For functional testing, it may be perfectly reasonable to run mechanisms in a combination that may not be scientifically meaningful, as long as it is not mechanically harmful. For example, to save time, one might imagine running short-form functional test on the slit mask mechanism while operating the etalon mechanism prior to removing it.

4.4.4 Configuration VI

The Configuration VI presents the highest level of abstraction to the operator, and is the level at which the operator will run the instrument during the night. The Configuration VI presents an abstraction of the PFS that is scientifically and operationally meaningful to the night staff. Modes will be presented as choices such as “Spectropolarimetry” and “Fabry-Perot Imaging”. The Configuration VI will embody the knowledge of what has to be done with each mechanism (and in what order) to achieve the desired observational state of the PFIS.

It will render the status of the PFIS based on information passed up to it from the lower layers.

4.4.5 Simulation Mode

Our experience with the WIYN control system underscored the tremendous advantage offered by well-designed simulators. The modular nature and hierarchical structure of LabVIEW VIs allow a rapidly-prototyped implementation of the control system during the Critical Design phase. Each actuator and its associated sensors, indexes, and limits will be simulated within the actuator VI, in order that the VI that controls the actuator can be prototyped. The simulation mode will be selectable on the actuator VI user interface, and may also be invoked globally from inputs received from higher up in the control hierarchy.

The early development of such simulators, even if crude, will allow all levels of the control system to be prototyped, experimented with, discarded if necessary, and reworked based on a growing base of experience.

5 External Interfaces

Both the Detector Controller Subsystem and the Telescope Control Subsystem will have control and data acquisition interfaces developed as LabVIEW VIs. These interfaces are governed by the appropriate Interface Control Documents.

We suggest that the control and data interfaces specified in the Interface Control Documents also be embodied in the form of LabVIEW VIs, whose input and output behavior implement the contents of the appropriate ICDs. This has two important benefits: the detailed requirements can be specified in a machine-readable form ("proof by compilation"), and they can also serve during fabrication and testing as representations of the actual operational control interfaces.

5.1 Detector Controller Subsystem

The control and data interface between PFIS and the Detector Controller Subsystem is specified in the PFIS/SAAO ICD.

5.2 Telescope Control System

The PFIS will require command and data services from the TCS. This section presents a preliminary list of items.

Data from TCS to PFIS:

- Current time
- Status bits (slewing, settling, tracking, guiding, etc.)
- Target position (equatorial & topocentric)
- Telescope position (equatorial & topocentric)
- Guider errors (in pixel, topocentric & equatorial coordinates)

Commands from PFIS to TCS:

- Target position (equatorial & topocentric)
- Telescope offset (equatorial & topocentric)

6 Power Budget

The SALT System Specification places severe restrictions on power dissipation, especially in the beam where PFIS will operate. PFIS will mitigate its power dissipation in several ways.

- Low duty cycle. Many PFIS mechanisms use small or medium stepper motors to configure the instrument before an observation, but not during it. The times of actuation are short compared to the expected average length of observations.
- Pneumatics. The actuation of large optics (etalons) or high power components (shutter holding solenoids) will be implemented using pneumatic cylinders.
- Glycol cooling. Some items (CCD array controller chassis, array controller power supply) will be cooled with facility glycol.
- Moving items out of the beam. The etalon controllers and the Cryotiger compressor will be located on the main floor, in the Igloo, out of the beam.

The spreadsheet in Section 2 above lists the estimated power, duration of operation, and emitted energy for each actuator. The time-averaged power for PFIS, assuming 1-hour observations, is about 2 watts.

A significant source of heat is the power supply for the array controller, which is advertised as 44 watts. This box will be mounted on the PFIS structure in a glycol-cooled box.