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MONSOON

Image Acquisition System (Pixel Server)

Operational Concepts Definition Document (OCDD)

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Version	Date Approved	Sections Affected	Remarks

Identification

It is NOAO Document # XXXXXXXXXX.

Document Acceptance and Concurrence

This document represents the current understanding of the functional, performance and operational characteristics of the MONSOON Image Acquisition System to be developed at NOAO and deployed on systems at Kitt Peak National Observatory (KPNO) and at the Cerro Tololo International Observatory (CTIO)

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Preface

This is an initial draft, submitted for discussion and comment.

This document is intended to outline from a "user's perspective" the operational characteristics for a new image acquisition system named MONSOON to be used for the next generation imaging system requirements at NOAO. The scope of this document has been expanded from characterization of a "detector controller" to "image acquisition system" in order to address the fact that our vision on imaging system designs, especially those employing large format detectors and large mosaic systems, needs to address more than just the detector interface. It must also concentrate on the significant issues associated with image data flow, processing and management.

This operational concept definition effort has been undertaken because existing NOAO controller architectures have been deemed inadequate to provide the necessary performance for the next generation imaging systems. This is due to 3 primary reasons: large channels counts, fast readouts, and obsolete components in existing systems. This development is driven in the near term by the 2K x 2K IR FPA developments (ORION, and HAWAII-2), and by near-future needs in IR and CCD MOSAIC projects.

This document is intended to communicate overall quantitative and qualitative system characteristics to the users, developers, and support staff. It is used to describe the user organizations, missions, and organizational objectives from an integrated systems point of view.

To serve this function system models have been included to aid and promote discussion on relevant topics. In your review, please focus on "**what**" the project requirements are, "**when**" they are needed, and "**why**" they are needed. Do not concentrate at this time on "how" the project should be accomplished or "who" should do what, this will occur later. However, any known constraints in resources, time, existing systems, etc. should be detailed. Feel free to make suggestions on format and content. Please attempt to provide the fundamental reasons for requirements not the derived ones. For example, image "subrastering". This is often a requirement to support focus sequences. The underlying issue here is focus time, and improving observing efficiency. Now "subrastering" an image is one way to reduce readout time to improve focus efficiency, however if an entire image can be readout in an appropriate time then subrastering may be unnecessary. Focussing is an example where a reduced readnoise performance could be traded for a reduced readout time. The point here is to attempt to set system requirements based on the "true" need. Please also submit the source of any and all requirements or constraints so that if a

future tradeoff or system design issue comes up later in the project the appropriate authority can be consulted.

Document Scope

This Operational Concept Definition Document (OCDD) is a user-oriented document that describes system characteristics of the MONSOON Image Acquisition System from a user's viewpoint. This document is the top-level development document for the MONSOON Image Acquisition System. All other MONSOON Documents are considered required to be in compliance with the characteristics outlined in this document. Physical implementation details are not included, except where they represent a defined system constraint which must be addressed.

Document Overview

The OCDD is modeled after the IEEE Concept of Operations (ConOps) Document referenced below in section 2. It is intended to communicate overall quantitative and qualitative system characteristics to the users, developers, and support staff at NOAO. The OCDD is largely based on the initial NDAS Project Concept Definition Document that was circulated for internal and external review in February of 2001. The NDAS Project Concept transitioned to the MONSOON Project during August of 2001.

The follow-on document to the OCDD is the MONSOON Functional Performance and Requirements Document (FPRD) where additional detail and constraints will be added and will serve essentially as the top-level system specification.

The intended audience for this document is the Scientific and Technical Staff at NOAO and elsewhere in the astronomical community who are stakeholders in the MONSOON system. A stakeholder is any individual who either uses, supports, or is in some way affected by this system.

1.0 Introduction

1.1 System Overview

Astronomy continues to move in the direction of larger telescopes, equipped with instrumentation supportive of higher spatial/spectral resolution, and larger image fields. Not surprisingly advances in observational astronomy in both the OUV and the IR are still paced by advances in detector technology. Within the last quarter century, infrared detectors have evolved from individual discrete devices to high tech aggregates of millions of pixels. The science drivers for yet more pixels have kept apace - already several projects are dependent on large multiples 4K x 4K OUV arrays and modest numbers of 2K x 2K IR arrays to reach their goals and next generation facilities envision focal planes paved with detector tiles. To service such focal plane composites requires sophisticated control of multiple devices, but management of the digitized data flow off the focal plan through the data pipeline to the investigator and the archive looms equally large. These efforts drive the need for larger and larger imaging focal planes. One cannot populate a wide field of view without an assured supply of high quality, moderately priced, well-characterized devices in large numbers. To meet this need tremendous effort has been expended in the development of high resolution imaging devices (4K x 4K CCDs, 2K x 2K IR Focal Plane Arrays). The significant increase in individual device size, while impressive, has not alone been sufficient to meet demand for focal plane resolution. Larger focal planes have increasingly been created through the use of mosaicing techniques, first with CCDs and now with IRFPAs.

In addition to the increased spatial/spectral resolution of these focal planes, radiometric sensitivity across the spectrum has also increased by over an order of magnitude within the recent past. This dramatic improvement in science capability has been realized through the cumulative effect of:

- increased light capturing power of the large 8-meter class telescopes
- increased throughput and reduced background of contemporary OUV/IR systems
- improved quantum efficiency and reduced readnoise of imaging devices

The astronomical grasp of a system, as measured by the system throughput $A\Omega$ (product of the collecting area with the field of view) will undergo yet another order of magnitude increase as large, mosaiced focal planes are fielded over the coming decade. The sheer physical size of these devices has increased the need for faster readout and more acquisition channels. This need has been met with improvements in device fabrication, particularly CCD output structures and FPA multiplexors. It is the combined need for more channels, faster readout, and lower noise which has made the current suite of NOAO controllers inadequate.

The wide range of systems currently under development or in the planning stages at NOAO, has driven the need for scalable multi-channel high-speed image acquisition. New challenges have been raised, in particular by the mosaic projects, in terms of communication bandwidth, data storage and data processing requirements. In order to meet this demand, new requirements for a not only a new detector controller but rather a new image acquisition architecture, need to be defined. This concept can and should be extended to include the data processing pipelines which are not addressed in this document.

These large scale imaging systems have also raised concerns in areas of controller design which have frequently received cursory attention in prior designs, including:

- physical size and form factor issues.
- power dissipation and cooling near the telescope.
- system assembly, test, and integration time.
- reliability and the cost of operation.
- data integrity, stability, and verification.

These are serious concerns for these larger systems, especially if we desire to build quality instruments on time and under budget. These are significant issues which have not always been adequately addressed in previous generation systems. These issues become increasingly important as instrument and telescope budgets soar in the current era of 8-10 meter class telescopes. Telescope time will become an even more valuable and costly commodity in the future as telescopes become even larger.

Real efforts have been made to look outside of the astronomical community for solutions found in other disciplines to similar classes of problems. A large number of the challenges raised by these system needs are already being successfully faced in other areas such as telecommunications, laboratory instrumentation, aerospace, and others. Efforts have also been made to use true commercial off the shelf (COTS) system elements, and find truly technology independent solutions for a number of system design issues. The entire system design should not be tied to one small vendor or potentially obsolescent technology (SDSU Controllers/ INMOS transputers).

There is another significant development area in imaging devices which impacts the data acquisition system design and should be of obvious concern. A number of current R&D efforts are focussed on the development of focal plane interface electronics at the imaging device level. The future of imaging devices may eventually become "photons in bits out". This technology has already been implemented in other sectors beyond astronomy. From a system level electrical interface standpoint, it does not matter greatly whether this takes the form of an integrated monolithic imaging device (CMOS e.g.), a hybrid form such as that used in IR FPAs (sensor array mated to a digitizing readout circuit), or in a closely integrated sensor chip assembly where the interface electronics is in the form of an ASIC mounted closely to the imaging device. The system interface implication of this is that system designers may no longer need to provide an "analog interface" (clocks, biases and digitization), but rather simply a "digital interface". This would lend itself to system design considering a "bits to FITS" approach.

The point is this, any new image acquisition system design should:

- provide detector limited performance.
- attempt to embrace all the relevant imaging devices and systems currently existing, in the planning stages, or on the visible horizon.
- consider the "total" view of the observatory as an integrated system where the output is high-quality science data ready to fuel the production of scientific papers and the advancement of astronomy.
- maximize "open-shutter" integration time, by minimizing losses due to overheads and downtime due to system failures, thereby maximizing observing time.

This forward looking approach will undoubtedly move our efforts toward developing a modular, scalable architecture, which addresses the data pipelines and information flow issues, not simply device interface. As a tool to promote understanding between system components the Observatory System Reference Model is shown in Figure 1 on the following page. It serves to illustrate a functional model of a typical modern astronomical

observatory. The functional entities shown in this model are often grouped together in various physical elements, and certainly additional detail can be included, but the basic underlying associations and structure remains valid.

This model is presented to advance the dialog for a complete view of the observatory as an integrated image collection system. Important issues such as supporting observing sequences such as dithering, mosaicing, focussing, etc. which require the control of the telescope and or the instrument configuration should be addressed at a layer above the image acquisition system in order to "well coordinate" these activities into the observatory framework. A key component in this model is the "Image Handling System". Issues such as data calibration and reduction which fall in this functional area are absolutely paramount to overall system success.

OBSERVATORY SYSTEM REFERENCE MODEL

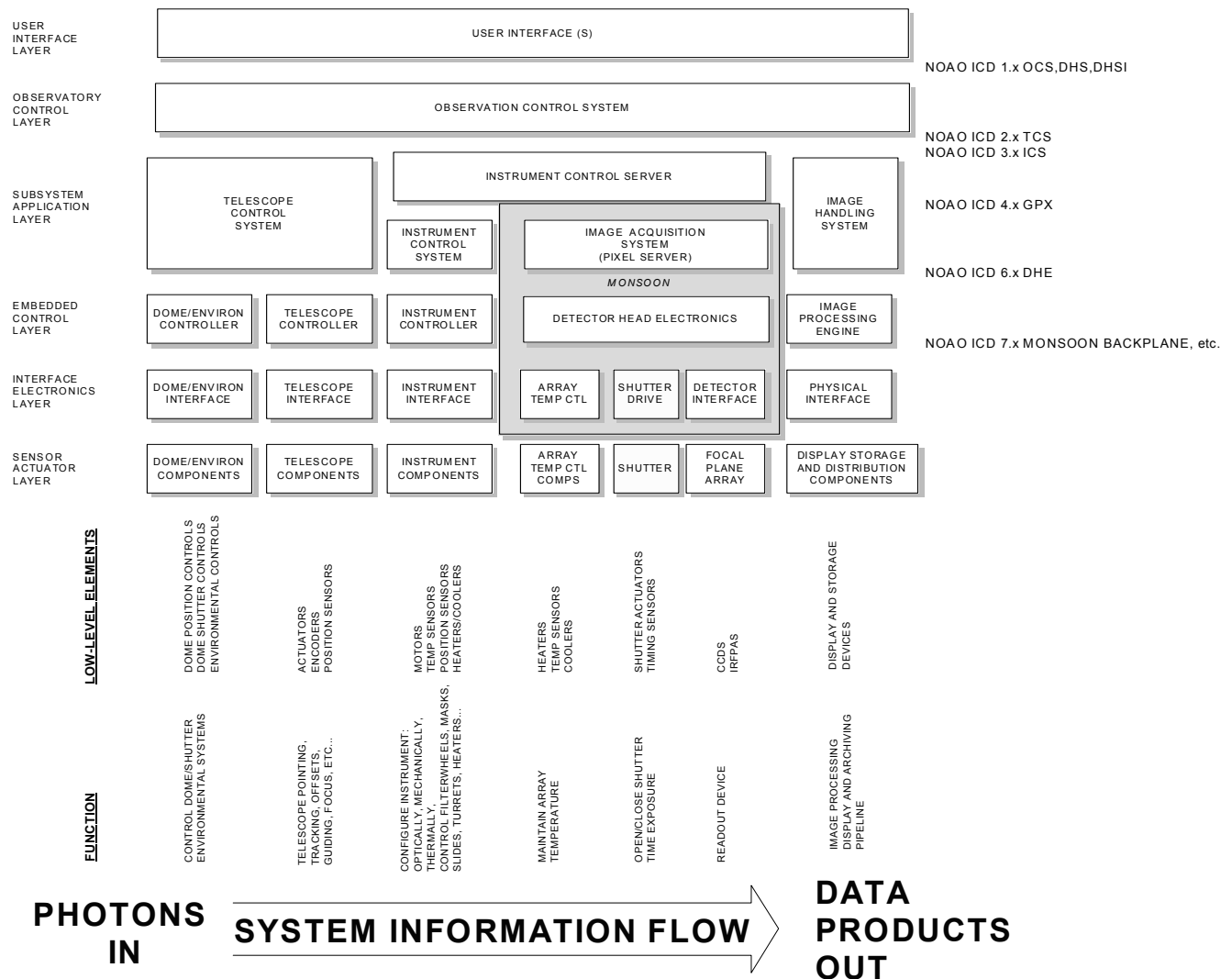


Figure 1 **Observatory System Reference Model.** Illustrates the major components found in a typical ground-based astronomical observatory, and their relation to each other. Model shows functional elements, not physical elements, functions may be combined in a variety of physical implementations and groupings.

In Figure 1, shown above, note the NOAO ICDs detailed at the right side of the model. These documents will provide much needed rationalization of the key interfaces in the observatory between major systems. The ICDS 4.0 GPX, ICD 6.0 and 6.1 DHE, as well as the ICD 7.0 DHE Backplane are currently released in draft form and under internal and external review. Higher level ICDs will be developed in the near term.

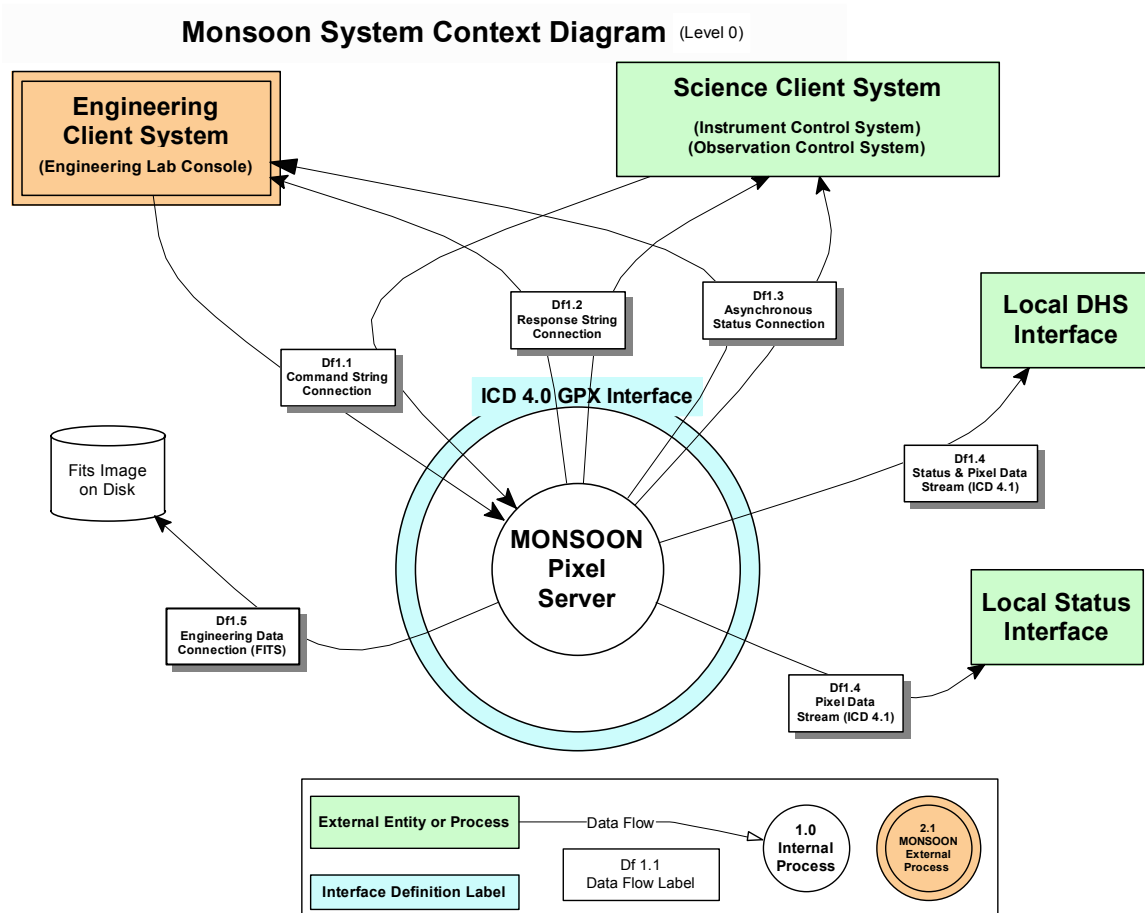


Figure 2 **MONSOON Context Level System Data Flow Diagram**. Shows the major data flows into and out of the MONSOON to external entities which are functionally shown as interfaced through the Instrument Control Layer in the Observatory System reference Model in Figure 1 above. Observatory systems includes Telescope Control, Instrument Control, and Observatory Control.

Figure 2, shown above, shows the MONSOON system in relation to the defined external systems that it must interface to. This provides a clear picture of how MONSOON fits into the observatory model.

1.2 Acronyms

ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
DHE	Detector Head Electronics
DHS	Data Handling System
FITS	Flexible Image Transport System
FPA	Focal Plane Array
GPX	Generic Pixel Server

MONSOON	Not an acronym
ICD	Interface Control Document
ICS	Instrument Control System
ID	Identifier
IR	Infrared
LAN	Local Area Network
N/A	Not Applicable
OCS	Observatory Control System
ROI	Region of Interest
TBD	To Be Decided

1.3 Glossary

Attribute - An entity which describes some aspect of the configuration of a system, subsystem, or component, such as the level of a voltage or the state of a shutter. Certain attributes will be used by as command parameters. The OCS communicates with a science instrument by sending it sets of "attributes" and "**values**".

Command - An instruction commanding a system to start some action. The action may result in a voltage changing or some internal parameters being set to particular values. A command may have command parameters (aka. "arguments") which contain the details of the instruction to be obeyed.

Pixel Acquisition Node (PAN)- A component of the MONSOON Image Acquisition System or Pixel Server. The PAN is the computer and associated software which the interface to the Detector Head Electronics (DHE) and provide the image pre-processing of the data stream from the DHE. The PAN was formerly referred to as the Data Acquisition Node in previous MONSOON Documentation.

Data array -The data, while it is stored in data processing memory, which resulted from one or more readouts of an IR array or CCD detector.

Data Set - A self-contained collection of data generated as a result of an Pixel Server obeying a gpxStartExp command. Each gpxStartExp command results in one and only one data set.

Exposure - The name used to describe the process and the data resulting from the activity of resetting/clearing a detector, exposing it to photons and then reading out the data. This may include multiple sample readout techniques such as Fowler sampling, sample up the ramp, etc. (For example, an exposure would be the **data array** which results when a single Reset-Readout-Integrate-Readout cycle is performed on an IR detector or a single CCD Clear-Integrate-Readout cycle.)

Single Exposure Sequence - Exposure sequence where all exposure parameters are fixed and the detector is readout (1 to N) times and combined to form a single image. Examples would be a simple reset read cycle of a classic CCD or IR detector, Fowler Sampling, Coadditions of Images, Orthogonal Transfer Imaging (Guide Region Readout followed by centroid calculation followed by image shift, n times til final image formed). .

Multiple Exposure Sequence - Exposure sequences with potentially varied exposure configurations and the data stored as multiple images. Examples would test routines such as the Photon Transfer Curve, multiple time-stamped exposures, multiple exposures synched to an external source such as a AO system or Chopper system.

Frame - A frame is the result of one or more readouts of an array averaged pixel by pixel. Each **frame** represents the signal values obtained from reading the entire ROI being read out of the detector. Multiple **frames** may be processed into a single **exposure**.

Image - The array of detector pixel and description data representing a science or diagnostic image or spectrum. An **image** is capable of being displayed or processed as a discrete entity. The values in the array may be stored in memory or on disk and are related to the data taken by the detector by some processing algorithm, (for example an **image** may consist of all the coadded and averaged **exposures** in one beam of a chop mode gpxStartExp command).

Observation - The process of exposing the detector to photons in one or more exposures. The result of an observation is a **picture??? Observation Data Set???? Image????**.

Readout - When used as a noun to describe instrument data, this refers to a single read of every pixel in the detector region of interest. A one or more readouts can be averaged pixel by pixel to create a **frame**.

ROI - A **Region of Interest** is a sub array of the available detector area. There are two types of sub-arrays, which can be defined. The Sequence ROI is an ROI on the active surface of the array used to increase the frequency of the Array readout. The Data Reduction ROI is an arbitrary rectangle of any size, which fits on the Array. Data Reduction ROI's are defined to reduce the volume of data sent to the disk or DHS even when the entire Array is being read out.

Value - The value associated with an "attribute".

Detector Head Electronics (DHE)- A component of the MONSOON Image Acquisition System or Pixel Server. The lowest level MONSOON subsystem, normally closely connected to the detector and the dewar in which the detector resides for signal integrity issues. The DHE connects to the PAN through a fiberoptic interface cable. Previously called the MONSOON Detector Controller.

Pixel Server - A system that produces images when requested to do so by some client system. The MONSOON Image Acquisition System is a Pixel Server.

Generic Pixel Server Interface- A pixel server command and data interface that conforms to the **GPX** Interface description. The goal is to allow multiple pixel server implementations conform to the same interface definition.

Supervisory Node. A component of the MONSOON Image Acquisition System or Pixel Server. The Supervisory Node is the software layer that coordinates multiple Pixel Acquisition Node – Detector Head Electronics node pairs into a single integrated system. In the event where only a single PAN-DHE node pair is needed the Supervisory layer is not needed. The Supervisory Layer and the PAN all adhere to the GPX interface defined above, and in the case of a single PAN-DHE node pair can be simply removed from the system if desired. If used in the system the Supervisory Node may run on a separate computer networked to the PANs or be physically running on a specific computer along with on of the PANs.

1.4 Referenced Documents

- 1) SPE-C-G0037, "Software Design Description", Gemini 8m Telescopes Project.
- 2) "ICD/16 — The Parameter Definition Format", Steve Wampler, Gemini 8m Telescopes Project.
- 3) WHT-PDF-1, "FITS headers for WHT FITS tapes", Steve Unger, Guy Rixon & Frank Gribbin, RGO.
- 4) NOST 100-1.0, "Definition of the Flexible Image Transport System (FITS)", NASA Office of Standards and Technology.
- 5) GEN-SPE-ESO-00000-794, "ESO Data Interface Control Document", Miguel Albrecht, ESO.
- 6) IEEE Std 610.12-1990 - "IEEE standard glossary of software engineering terminology", Standards Coordinating Committee of the IEEE Computer Society, USA, 19901210
- 7) ANSI/IEEE Std 754-1985 - "IEEE Standard for binary floating-point arithmetic" - Standards Committee of the IEEE Computer Society, USA 19850812
- 8) xxxx "XDR - Extended data representation Standard" ????
- 9) NOAO Document ###.###&&& - ICD 4.0 Version 0.1.2 - "Generic Pixel Server-Communications, Command/Response and Data Stream Interface Description", Nick C. Buchholz(NOAO), Barry M. Starr(NOAO), 20020308

- 10) NOAO Document ###.###.&&& - ICD 6.0 Version 0.1.2 - "Generic Detector Head Electronics - Command and Data Stream Interface Description", Nick C. Buchholz(NOAO), Barry M. Starr(NOAO), 20020308
- 11) NOAO Document ###.###.&&& - ICD 6.1 Version 0.1.2 - "MONSOON DHE - Command and Data Stream Interface Implementation Description", Nick C. Buchholz(NOAO), Barry M. Starr(NOAO), 20020308
- 12) NEWFIRM OCDD
- 13) NEWFIRM FPRD
- 14) GSAOI OCDD FPRD
- 15) QUOTA ATI Proposal
- 16) ODI
- 17) ORION
- 18) Rockwell Documents
- 19) RIO Docs
- 20) Lincoln Docs
- 21) EEV Docs
- 22) NDAS PCCD
- 23) MONSOON System Description

2.0 Current Systems

This section describes the existing NOAO systems for image acquisition.

2.1 Background, Objectives, and Scope

NOAO has a long-standing tradition of providing high-quality, high performance detector controller systems. These systems have served KPNO and CTIO admirably since the beginning of electronic imaging in astronomy. Owing to the continued advance of technology, which has rendered key components both unavailable and obsolete, these systems are neither desirable nor capable of replication for new instrumentation. A new paradigm is required both for new systems and as replacement for selected systems already deployed.

2.2 Operational Policies and Constraints

Existing systems have served two primary functions:

- provide for acquisition of science data at the observatory.
- provide for detector test and characterization in the laboratory.

For the observatory, the operational constraints on the systems have been to interface to the extant observatory environment and the relevant interacting systems in an effective and reliable manner, and to provide high-quality science data. For the laboratory, the need is to enable a comprehensive test capability to promote efficient detector characterization, optimization, and deployment.

2.3 Description of Current Systems

The detector control systems in Current use at NOAO are of 7 main types, 4 systems for OUV CCD control and 3 systems to control IR FPA's

The NOAO CCD systems are:

- NOAO AMD2901 based controller in use at KPNO since 1984. These electronics are mated to individual CCD camera packages.
- NOAO ARCON controller is use at both CTIO and KPNO
- NOAO HARCON (Hybrid ARCON) based systems in use at the WIYN facility at KPNO. The HARCON uses an ARCON digital system (sequencer, fiber link) and a 2901 Analog Front-End (Clock and Bias, Video Processor, ADC).
- SDSU-II CCD Controller at the SOAR facility on Cerro Pachon.

The IR systems are:

- NOAO Wildfire Systems and variants used on Phoenix, ABU, SQIID and in the IR Lab. Retired systems include IRIM, CRSP, CIRIM, CIRS and COB.
- NOAO Gemini Array Controller used on GNIRS and NIRI at Gemini.
- SDSU-II IR Controller used on ISPI at CTIO.

Since these were the formative years, it comes as no great surprise that the scope of these systems and their attendant software functionality are as diverse as they are variant. For example, each Wildfire system shares significant components, including the software architecture, communications hardware, and off instrument hardware with its brethren. However, due in no small part to fundamental differences in requirements/capabilities, the rapid changes in technology for both the detectors and the electronics, and the evolution in our understanding of the natural limitations of astronomical observation, the instrument

side components – the so-called Detector Head Electronics are unique to each instrument. The description of these systems is beyond the scope of this document.

2.4 Modes of Operation for the Current Systems

The image acquisition systems currently in use within NOAO serve three basic missions:

- Detector research and development within the NOAO Detector Research and Development laboratory activities for both IR and OUV devices.
- Instrument development in the lab and at the observatory for all the array-based OUV and IR instrumentation constructed by NOAO.
- Science operations at multiple NOAO-related, ground-based astronomical observatory environments by KPNO, CTIO, and Gemini.

These core missions are accomplished through 6 basic modes of operation:

Science Observing
System Calibration
System Diagnostics
Detector Research and Development
Detector Characterization
Instrument Development

2.4.1 Science Observing Modes

Astronomical observation employs a wide variety of techniques to obtain repeatable, well-calibrated data that can be combined in various ways to extract and reconstruct the science target from the background with high sensitivity. The science observing modes supported by the ensemble of extant systems during routine science operations.

2.4.1.1 Sequence Control

Astronomical observations are accomplished through orchestrated sequences of image taking interspersed with changes in position on the sky, and/or changes in instrument configuration (such as filter or grating setting). The following techniques depend on determinate sequencing of telescope and array control systems:

- **Offsetting** – an incremental change in telescope pointing relative to a defined position on the sky.
- **Dithering** – observation of a sequence of (random or patterned) spatial positions spanning a small pixel interval for removing detector artifacts.
- **Micro-stepping** - observation of a sequence of spatial positions that sample the target point spread function at determinate sub-pixel intervals for image reconstruction.
- **Chopping** – synchronous observation of a set of two or three fixed spatial positions, accomplished by the rapid transition (2-10Hz) of a chopping secondary, for observations at thermal wavelengths.
- **Nodding** – observations at a pair of spatial positions with fixed separation, accomplished through frequent (5-30sec) telescope motion used either in conjunction with or in place of chopping for observations at thermal wavelengths.
- **Mosaicing** – observations at a sequence of grid of overlapping spatial positions for reconstructing for accurate mapping of regions smaller than the spatial footprint of the focal plane array on the sky.

- **Drift Scanning** – observing technique that synchronizes telescope motion with the detector readout along the charge transfer axis, so that the image continues to accumulate as it is read out.
- **Nod and Shuffle** – CCD spectroscopic observing technique that accumulates sky and target observations on chip, synchronizing bi-directional charge transfer with telescope nodding for accurate subtraction of sky emission lines.
- **Speckle Mode** – assorted techniques involving spatial scanning and/or very fast reads of subrasters to extract high angular resolution images within a restricted FOV in the presence of seeing.

2.4.1.2 External Time Stamping

Accurate (with latency both fixed and determinate) association of a standard observatory time with an observation, such as recording the start and/or end of an observation

2.4.1.3 Exposure Control Modes

Selection of integration time synchronized with shutter motion where applicable and type of readout for observations of target, bias, dark, reference, flat

2.4.1.4 Device Control Modes

Selection of specific modes of array readout at the device level

2.4.1.4.a Device Output Selection - Selection of the specific devices within a mosaiced focal plane that are active and which analog outputs are enabled for each device

2.4.1.4.b Pixel Readout Modes

- Standard – One Pixel, Single Read
- Digital Averaging – One Pixel, Multiple Reads
- Binning – Multiple Pixels, Single Read

2.4.1.4.c Pixel Reset Modes (IR)

- **Pixel_Reset.** Each pixel is independently addressed and individually reset.
- **Ripple_Reset.** Each row (or row pair) of pixels is independently addressed and reset at the same time.
- **Global_Reset.** All the pixels are reset at the same time.

2.4.1.4.d Detector Sampling modes

- **IR Fast Readout** – single frame (reset | read) for high background
- Single CDS Readout
 - IR - difference of two full frames (reset | non-destructive read | accumulate charge | read)
 - CCD
- IR Fowler Sampling
- IR Sample-Up-The-Ramp - fixed time intervals through readout
- Pixel by Pixel (2^N Samples Only) –provides digital filtering of the video signal

2.4.1.4.e Region of Interest Selection

- Single ROI
- Multiple ROI

2.4.1.5 Frame Accumulation Modes

2.4.1.5.a Simple co-addition - accumulation of a sequence of frames with one output image. Used at high background to improve efficiency by restricting the number of frames passed through the data pipeline to storage

2.4.1.5.b Multiple co-addition - accumulation of sequence of frames in collated multiple output images, such as two chop/nod positions

2.4.2 System Calibration Modes

The extant systems provide the capabilities to support the calibration modes noted below.

2.4.2.1 Focus Sequences

2.4.2.2 Darks

2.4.2.3 Bias frames

2.4.2.4 Flat Fields

2.4.3 System Diagnostic Modes

The MONSOON System must provide extensive remote diagnostic capability to permit efficient determination of system status and timely recovery from error states.

2.4.4 Detector Research and Development Modes

The MONSOON System must provide an effective solution for automated device characterization such as that needed for effective test and optimization of a large number of detectors represented by the next generation systems described previously.

- Photon Transfer Curve
- QE Tests
- CTE Tests
- Dark Current Measurements
- Conversion Gain
- Read Noise measurements
- Reference channel operations

2.5 User Classes and Other Involved Personnel

There are 4 main users classes for the systems are:

- Scientific Observers
- Technical Development Staff
- Technical Support Staff
- Detector Research and Development Staff

It is well understood that these four user classes may be embodied by a single individual, as is often the case in ground-based astronomy, or may be distinct groups of individuals. The class distinctions are still valid for system analysis purposes.

2.5.1 Scientific Observers

The astronomers and astrophysicists who use the observatory for the advancement of scientific goals

2.5.2 Technical Development Staff

The scientists, engineers, technicians, and programmers who are responsible for instrumentation development

2.5.3 Technical Support Staff

The scientists, engineers, technicians, and programmers who are responsible for instrumentation support after initial deployment

2.5.4 Detector Research and Development Staff

The scientists, engineers, technicians, and programmers who are responsible for detector research and development activities

2.6 Support Environment

Both the intellectual value of assigned observing time in meeting science goals and its fiduciary value in terms of operational cost make system reliability a primary concern. The remote mountain sites where these systems are deployed are difficult to reach in a timely fashion and the on-site environment is itself not conducive to sophisticated diagnosis of subtle malfunction. As such, the additional effort devoted to system reliability, along with provision of a remote diagnostic and intervention capability must be considered a requirement, not an option.

3.0 Justification for and Nature of Change

Owing to the obsolescence of key components in a number of the existing systems, as well as the expanded requirements in scale, performance, reliability, and flexibility presented by the next-generation systems a new scalable, large channel count system architecture needs to be developed.

3.1 Justification of Changes

The MONSOON System will provide a cost-effective, high-performance, compact form-factor, low-power scalable architecture for the 6 modes of operation defined in the above section 2.4. In this interest of easing operational impacts and simplifying the current system structure the MONSOON system will support not only the existing CCD and IR Detectors currently in operation but provide the capability to adapt to and support all anticipated future device providing detector limited performance.

MONSOON is currently specified for the following applications:

- ORION: 2K x 2K InSb Test Set
- NEWFIRM: 4K x 4K IR Mosaic camera for the KPNO 4meter
- GSAOI: 4K x 4K IR Mosaic camera for the Gemini MCAO system.
- OUV Detector Characterization Test Set
- LBNL Mosaic.
- QUOTA 8K x 8K OTCCD Mosaic camera for WYIN

Potential systems include:

- WYIN 8K x 8K Lincoln Labs CCID-20 Mosaic
- ODI (One Degree Imager) proposed for the WYIN Telescope
- LSST (Large Synoptic Survey Telescope)
- TSIP Instruments
- SWIFT Instruments
- GSMT Instruments
- NGST Detector Lab Support
- UH PANSTARS (formerly POI) Project

Potential ASTEROID Collaboration systems from:

- KECK
- Lick
- Palomar
- CELT

Potential Backup of Wildfire based instrumentation:

- Phoenix @ SOAR/Gemini South
- SQUID @ KPNO

Potential Backup of ARCON/HARCON based instrumentation:

- MOSAIC @ KPNO
- MiniMOSAIC @ WYIN
- MOSAIC II@ CTIO

Potential Upgrade of SDSU-II based instrumentation:

- ISPI@ CTIO

3.2 Description of Desired Changes

3.2.1 Priorities Among Changes

- 1) ORION Test and Characterization
- 2) NEWFIRM Project Development
- 3) GSAOI Project Development
- 4) OUV Device Characterization
- 5) LBNL MOSAIC Development
- 6) WYIN Tip-Tilt LL CCID-20 Camera
- 7) QUOTA Project Development

3.2.2 Changes Considered and Not Included

Adding additional capabilities to MONSOON to provide the needs of typical instrument control functions such as auxiliary control functions that are not directly part of the detector interface but are closely linked include the following:

- Exposure Time Stamping
- Vacuum Measurement
- Mechanism Control (Filter wheels, Gratings, Slides, etc)
- Cryogen Level Detection

While the MONSOON System design can easily support these capabilities they are considered outside of the current system scope.

4.0 Concepts for Proposed System

4.1 Background, Objectives, and Scope

The NOAO staff, both north and south combined, has extensive experience in the design, development, fabrication, and use of these types of systems. This experience transcends institutions from across the astronomical community as well as aerospace and commercial enterprises. The talent, experience, motivation, initiative, and capability to produce MONSOON are resident and ready to take on the challenge.

The benefits of a single unified approach to NOAO's imaging needs through development of a common framework to support all detector technologies from a single platform is well known. This is increasingly important as we are trying to do more ambitious

projects with fewer staff. To service the diverse needs of the next generation of instruments in an era of finite resources, one has neither the time, nor the capital, nor the personnel to start afresh with each new system. Rather, one must consider the "total" view of the observatory as an integrated system where the output is high-quality science data ready to fuel the production of scientific papers and the advancement of astronomy. By focusing on a single unified design approach which has the flexibility to operate any array optimally, at least in principle, one might actually gain the full benefits of Non-Recurring Engineering cost while reducing unit production cost and the costs associated with each new application. The MONSOON system has both the opportunity and the charge to:

- Maximize "open-shutter" integration time, by minimizing losses due to overheads and downtime due to system failures, thereby maximizing observing time – extending the science grasp.
- Address physical size and form factor issues – large systems of unwieldy shape are difficult to deploy on a variety of instruments.
- Power dissipation and cooling near the telescope – to limit heat and turbulence along the target line of sight that can significantly degrade seeing.
- System assembly, test, and integration time – to meet cost and schedule.
- Reliability and the cost of operation – to permit relentless observing.
- Data integrity, stability, and verification – to produce quality science.

Most so-called array controllers perform a plethora of additional tasks, including instrument configuration and control, which not only needlessly complicates the design (at the risk of limiting performance), but also leads to unique systems that are difficult to support and maintain and that are not readily adapted to evolving needs. In the interest of project success, scope has been limited to the well-defined boundaries of a "**pixel server**". Consistent with NOAO's needs and resources, the higher-level functions of telescope command and instrument control have been moved to a more appropriate level of implementation, rather than being imbedded in the "**detector controller**". In addition current technology and the improvement in communication networks favors this modularized design approach to observatory systems.

The rising cost of focal planes, instruments, and telescope time demands that we provide detector limited performance in our image acquisition systems. The technology and talent exist to accomplish this with modest resources. It should be prioritized and acted upon immediately. This forward look should address not only current devices but those under development and discussion as well.

Detector Limited Performance - The fundamental objective is to enable observations which are not limited in either execution, cadence, or level of performance by the MONSOON system. Rather, observations are performed efficiently using optimal techniques and are appropriately limited by either the shot noise of the background or the intrinsic read noise of the detector. We use the phrase "**Detector Limited Performance**" to encompass this dictum.

Active Device List (Note: Many of these devices will likely be mosaiced)

RIO (SBRC) Devices

ORION 2Kx2K InSb

ALADDIN 1Kx1K InSb

HgCdTe/Silicon Diodes on Mux

Rockwell Devices

HAWAII-1 1Kx1K HgCdTe

HAWAII-2 2Kx2K HgCdTe
HAWAII-2RG
HAWAII-2RG w/ASIC
5um HgCdTe/Silicon Diodes on Mux

MARCONI (EEV) Devices
Wide Range

Lincoln Labs Devices
CCID-20 2Kx4K
Orthogonal Transfer CCDs (OTCCDs)
Orthogonal Transfer Arrays (OTAs)

SITE Devices
Loral/Lesser/Bredauther/Lockheed Devices
Lawrence Livermore/Berkeley
High Resitivity "Thick" CCDs

4.2 Operational Policies and Constraints

The MONSOON system must serve two primary functions:

- provide for acquisition of science data at the observatory.
- provide for detector test and characterization in the laboratory.

The operational constraints for MONSOON will be to interface to existing systems at the observatories and their relevant interacting systems in an effective and reliable manner, and to provide high-quality science data. For the laboratory, the constraint is to provide a comprehensive test capability to promote efficient detector characterization, optimization, and deployment.

4.3 Description of Proposed Systems

MONSOON will be a modular scalable system suitable for science requirements, detector research and development, and guider and wavefront sensing.

It will function as a reliable remote image server or pixel server and provide a high-level interface where the details of the exposure are abstracted from the external client whether that is an ICS, OCS, etc. The exposure is requested in terms of a virtual focal plane where details of number of devices, readout channels, number of electronics or computational components, data paths, etc. can be ignored by the external client and seamlessly addressed by the MONSOON system. As such, MONSOON will provide a single point of communication and control to the external systems. It may be required to have multiple physical data links to meet the system data rate requirements for the largest scale systems such as LSST, but this does not require an alternation of the single point communication and control model.

Additionally a low-level engineering interface will be provided with expanded capability to support diagnostic and detector research and development activities. It is likely that this may be considered an external engineering client to the MONSOON Pixel Server. The details of implementation are left to the MONSOON System Architecture Document.

MONSOON will support multiple external clients with a priority and security mechanism appropriate to guarantee the safety of the system and integrity of the science data.

MONSOON will support the capability to add functionality to the core software system in the form of post image acquisition processing capabilities, such as a new descrambling data processing module, without requiring recompilation of the system software. It will allow the capability to add low-level parameters to the acquisition configuration process without recompilation of the system.

MONSOON will support extensive system status logging and diagnostic self testing. Additional detail provided is below in section 5.4.

4.4 Modes of Operation for the Proposed Systems

The proposed image acquisition systems serve three basic missions:

- Detector research and development within the NOAO Detector Research and Development laboratory activities for both IR and OUV devices
- Instrument development in the lab and at the observatory for all the array-based OUV and IR instrumentation constructed by NOAO
- Science operations at multiple NOAO-related, ground-based astronomical observatory environments by KPNO, CTIO, and Gemini

There are 6 basic modes of operation for the proposed system:

- 1) Science Observing
- 2) System Calibration
- 3) System Diagnostic
- 4) Detector Research and Development
- 5) Detector Characterization
- 6) Instrument Development

4.4.1 Science Observing Modes

Astronomical observation employs a wide variety of techniques to obtain repeatable, well-calibrated data that can be combined in various ways to extract and reconstruct the science target from the background with high sensitivity. The science observing modes supported by the ensemble of extant systems during routine science operations.

4.4.1.1 Sequence Control

Astronomical observations are accomplished through orchestrated sequences of image taking interspersed with changes in position on the sky, and/or changes in instrument configuration (such as filter or grating setting). The following techniques depend on determinate sequencing of telescope and array control systems:

- **Offsetting** – incremental change in telescope pointing relative to a defined position on the sky.
- **Dithering** – observation of a sequence of (random or patterned) spatial positions spanning a small pixel interval for removing detector artifacts.
- **Micro-stepping** - observation of a sequence of spatial positions that sample the target point spread function at determinate sub-pixel intervals for image reconstruction.
- **Chopping** – synchronous observation of a set of two or three fixed spatial positions, accomplished by the rapid transition (2-10Hz) of a chopping secondary, for observations at thermal wavelengths.
- **Nodding** – observations at a pair of spatial positions with fixed separation, accomplished through frequent (5-30sec) telescope motion used either in conjunction with or in place of chopping for observations at thermal wavelengths.

- **Mosaicing** – observations at a sequence of grid of overlapping spatial positions for reconstructing for accurate mapping of regions smaller than the spatial footprint of the focal plane array on the sky.
- **Drift Scanning** – observing technique that synchronizes telescope motion with the detector readout along the charge transfer axis, so that the image continues to accumulate as it is read out.
- **Nod and Shuffle** – CCD spectroscopic observing technique that accumulates sky and target observations on chip, synchronizing bi-directional charge transfer with telescope nodding for accurate subtraction of sky emission lines.
- **Speckle Mode** – assorted techniques involving spatial scanning and/or very fast reads of subrasters to extract high angular resolution images within a restricted FOV in the presence of seeing.

4.4.1.2 External Time Stamping

Accurate (with latency both fixed and determinate) association of a standard observatory time with an observation, such as recording the start and/or end of an observation

4.4.1.3 Exposure Control Modes

Selection of integration time synchronized with shutter motion where applicable and type of readout for observations of target, bias, dark, reference, flat

4.4.1.4 Device Control Modes

Selection of specific modes of array readout at the device level

4.4.1.4.a Device Output Selection - Selection of the specific devices within a mosaiced focal plane that are active and which analog outputs are enabled for each device

4.4.1.4.b Pixel Readout Modes

- **Standard** – One Pixel, Single Read
- **Digital Averaging** – One Pixel, Multiple Reads
- **Binning** – Multiple Pixels, Single Read

4.4.1.4.c Pixel Reset Modes (IR)

- **Pixel_Reset.** Each pixel is independently addressed and individually reset.
- **Ripple_Reset.** Each row (or row pair) of pixels is independently addressed and reset at the same time.
- **Global_Reset.** All the pixels are reset at the same time.

4.4.1.4.d Detector Sampling modes

- **IR Fast Readout** – single frame (reset | read) for high background
- **Single CDS Readout**
 - o IR - difference of two full frames (reset | non-destructive read | accumulate charge | read)
 - o CCD
- **IR Fowler Sampling**
- **IR Sample-Up-The-Ramp** - fixed time intervals through readout
- **Pixel by Pixel** (2^N Samples Only) –provides digital filtering of the video signal

4.4.1.4.e Region of Interest Selection

- **Single ROI**
- **Multiple ROI**

4.4.1.5 Frame Accumulation Modes

4.4.1.5.a Simple co-addition - accumulation of a sequence of frames with one output image. Used at high background to improve efficiency by restricting the number of frames passed through the data pipeline to storage

4.4.1.5.b Multiple co-addition - accumulation of sequence of frames in collated multiple output images, such as two chop/nod positions

4.4.1.6 Image Compensation

Astronomical observations often push device operations to their limits. Exposures can be both extremely short and extremely long. The light level can be both extremely faint and extremely bright. Such abuse has its consequences. A variety of operating techniques will be required to ameliorate these effects.

4.4.1.6.a Image Persistence - IR FPAs in particular occasionally suffer from a form of image persistence which leaves a residual portion of a previous exposure in the current exposure. This phenomenon is actually an enhanced dark signal that decays over time and is especially noticeable when the background changes dramatically or the exposure time is increased. A variety of techniques have been devised to reduce this deleterious effect.

4.4.1.6.b Reference Drift - Over time the video signal from a FPA is known to drift. It is currently unknown whether this is a fundamental characteristic of hybrid focal plane technology, an unfortunate aspect of the video signal chain, or - as is more likely - combination of both factors. During a long exposure, an uncompensated drift becomes the limiting system "noise", easily overwhelming the read noise and limiting system sensitivity. The latest IR FPA designs (Orion and HAWAII 2RG) incorporate reference channels to monitor this drift.

4.4.2 System Calibration Modes

The MONSOON System must provide the capabilities to support the optimal execution and calibration of science and engineering data. This will include but not be limited to:

4.4.2.1 Focus Sequences

4.4.2.2 Darks

4.4.2.3 Bias frames

4.4.2.4 Flat fields

4.4.3 System Diagnostic Modes

The MONSOON System must provide extensive remote diagnostic capability. This will include but not be limited to:

4.4.3.1 Power Supply Voltage and Current Readback

4.4.3.2 Clock and Bias Voltage Readback

4.4.3.3 Digital Communication Pathway Diagnostics

4.4.3.4 Generation of Predetermined Pattern Data

Generate known test pattern data in lieu of image data to test communication links and data reduction algorithms.

4.4.3.5 Multiple External Clients

MONSOON will provide for multiple clients to link to the system in order to monitor current system activity. One mode would be to allow the technical staff to monitor a current science readout.

4.4.4 Detector Research and Development Modes

The MONSOON System must provide an effective solution for automated device characterization such as that needed for effective test and optimization of a large number of detector represented by the next generation systems described previously. Existing systems require constant manual interaction by the Technical staff in order to accomplish this task. Included in this capability will be the automated control and readback of detector clock and bias voltages as well as timing patterns necessary to optimize device operation. The operational mode to be supported in this context would be to provide the capability to support scripting of a large number of images taken with a predetermined parameter variation over an extended period of time. An example of this would be optimization of CCD output stage parameters, overnight through the sequencing of multiple photon transfer curve tests sequences with varied parameters

4.4.4.1 Photon Transfer Curve

4.4.4.2 QE Tests

4.4.4.3 CTE Tests

4.4.4.4 Dark Current Measurements

4.4.4.5 Conversion Gain

4.4.4.6 Read Noise

4.4.4.7 Reference Channel Operations

4.4.4.8 Automated Adjustment of All Clock and Bias Voltages

4.4.4.9 Automated Adjustment of All Timing Patterns

4.5 User Classes and Other Involved Personnel

There are still the same 4 main users classes for the systems as outlined in section 2.5:

- Scientific Observers
- Technical Development Staff
- Technical Support Staff
- Detector Research and Development Staff

It is well understood that these four user classes may be embodied by a single individual, as is often the case in ground-based astronomy, or may be distinct groups of individuals. The class distinctions are still valid for system analysis purposes.

4.5.1 Scientific Observers

The astronomers and astrophysicists who use the observatory for the advancement of scientific goals

4.5.2 Technical Development Staff

The scientists, engineers, technicians, and programmers who are responsible for instrumentation development

4.5.3 Technical Support Staff

The scientists, engineers, technicians, and programmers who are responsible for instrumentation support after initial deployment

4.5.4 Detector Research and Development Staff

The scientists, engineers, technicians, and programmers who are responsible for detector research and development activities

4.6 Support Environment

The same support environment as listed in section 2.6 exists with reduced staff due to reallocation of internal funds within NOAO, along with a reduction in total funding profile due to NSF cutbacks. Because of this the importance of a unified system approach with increased reliability is increased over previous times.

Both the intellectual value of assigned observing time in meeting science goals and its fiduciary value in terms of operational cost make system reliability a primary concern. The remote mountain sites where these systems are deployed are difficult to reach in a timely fashion and the on-site environment is itself not conducive to sophisticated diagnosis of subtle malfunction. As such, the additional effort devoted to system reliability, along with provision of a remote diagnostic and intervention capability must be considered a requirement, not an option.

5.0 Operational Scenarios

5.1 CCD Science Scenario

5.2 IR Science Scenario

5.3 Calibration Scenario

5.4 Test and Characterization Scenario

5.5 Instrument Development Scenario

6.0 Summary of Impacts

6.1 Operational Impacts

Increased scientific output
Reduced system downtime
Reduced operation staff loading

6.2 Organizational Impacts

The significant organization impacts revolve around to key issues:

- The use of NOAO technical staff for MONSOON development
- The use of NOAO technical staff for MONSOON deployment

The capital cost is extremely modest as MONSOON will be designed using low-cost or free development tools and the component costs for the system will be under 100k???

6.3 Impacts During Development

The most significant anticipated impact during development is protection of NOAO staff from competing projects internally. The MONSOON staff must be assigned and protected for the project in order to meet schedule goals.

7.0 Analysis of the Proposed System

7.1 Summary of Improvements

The MONSOON System will:

- Provide detector limited performance.
- Be seen in a broader system concept sense with a view to the foreseeable future
- Attempt to embrace all the relevant imaging devices and systems currently existing, in the planning stages, or on the visible horizon.
- Consider the "total" view of the observatory as an integrated system where the output is high-quality science data ready to fuel the production of scientific papers and the advancement of astronomy.
- Maximize "open-shutter" integration time, by minimizing losses due to overheads and downtime due to system failures, thereby maximizing observing time.

7.2 Disadvantages and Limitations

None envisioned or anticipated.

7.3 Alternatives and Trade-Offs Considered

The following is a list of existing systems and subsystems (or key technologies) that have been investigated for possible use within MONSOON. Although as stated previously this document is not intended to define implementation strategies it is intended to serve as a operational concept definition document. To this end acquiring listings of possible system components to be investigated is of great value for the next phase of effort where implementation will occur. Existing systems may be utilized as a complete end-to-end solution, incorporated as a subassembly in a larger framework, or components of existing systems might be utilized in a new or different design

These systems will be evaluated on the basis of:

- 1) Performance
- 2) Total System Cost (Manpower and Materials)
 - a. Purchase Price
 - b. Integration Costs
 - c. Maintenance Costs
- 3) Availability
- 4) Vendor Support
- 5) Documentation
- 6) Calibration
- 7) Expected Lifetime
- 8) Power Consumption
- 9) Form Factor

Existing Systems include:

- | | |
|--|------------------------|
| • ESO FIERA | (CCDs) |
| • ESO IRACE | (IR Detectors) |
| • CFHT MEGACAM | (CCD) |
| • SAO MEGACAM | (CCD) |
| • IRTF SPEX/ Redline Controller | (IR Detectors) |
| • Subaru MESSIA/MFRONT Electronics | (CCD) |
| • MFRONT Electronics | (CCD used on QUEST) |
| • University of Florida FLAMINGOS | (IR Detectors) |
| • Italian National Observatory Controller | (CCD) |
| • SDSU II | (CCD and IR Detectors) |
| • PIXCELLENT | (CCD) |
| • National Instruments PXI Based Instrumentation | |

Note: There are a number of known "commercial" controllers that exist. However, none have been identified that provide the performance or fiberoptic interface requirements needed for astronomy.

Key technologies, which are currently identified as possible components of the MONSOON system include:

- Commercial 1Gb/s fiberoptic point-to-point links.
- High-speed low-cost PC computer processing platforms.
- Existing data acquisition software.
- Low-power high-speed monolithic CMOS 16-bit analog-to-digital converter technologies.

8.0 Notes

9.0 Appendices