ICIMACS, The Ohio State Instrument Control and IMage Acquisition System

Bruce Atwood, Jerry A. Mason, Kevin R. Duemmel, Thomas P. O'Brien, Richard W. Pogge, Daniel Pappalardo, and Brian Hartung

Imaging Sciences Laboratory, Department of Astronomy, Ohio State University, 174 W. 18th Ave., Columbus, Ohio 43210-1106.

Keywords
Infrared, Optical, Astronomical Instrument System

Abstract

The Ohio State Instrument Control and Image Acquisition System, ICIMACS, is the computer hardware and software used by all instruments developed by the Imaging Science Laboratory (ISL) to control the detector, pre-process data, record image data on a separate computer system for data reduction and analysis, generate real time data display, control the mechanisms within an instrument, interface with the telescope controller, connect to a user interface, and perform engineering functions such as temperature or pressure logging. ICIMACS has now been used on 12 different instruments and is herein described as applied to "MOSAIC" the near IR imager/spectrometer in use on the Kitt Peak 2.1 and 4 meter telescopes and on the MDM 2.4 and 1.3 meter telescopes.

1. INTRODUCTION

Ohio State has had an active astronomical instrumentation program for more than twenty years. Early efforts were organized, as they are in many university environments, for the construction of one specific instrument. First-time costs were a major factor in design choices and each new project was begun largely without regard for the details of previous efforts. Most notable of these early efforts are the IDS photon counting system and the CCD spectrograph both of which have had substantial success on the 1.8-m Perkins telescope at Lowell Observatory. About ten years ago the department, recognizing that their participation in the LBT project (then called the Columbus Project) as well as other instrumentation projects would benefit from a more systematic approach, formed what is now called the Imaging Sciences Laboratory (ISL). The ISL, with a significant number of permanent employees, was able to develop a complete and stable instrument development environment where previously tested designs serve for a large fraction of each new project. Care was taken to define an overall system architecture that would be long lived and extensible. Problems such as electronics packaging and cabling were addressed and internal standards were developed and are enforced to allow quick development of new projects. Robust sub-systems were developed for detector control, data handling, instrument control, telescope control, engineering data logging, and user interface. Equally important with these hardware designs and standards was the development of infrastructure and culture to allow the ISL to tackle the design and fabrication of new system with confidence. We viewed it as essential that we have access to first rate software for optical design, mechanical analysis, and electronic design. A very strong bias towards modular designs for both hardware and software has been adopted.
Finally, given our observation that software is the part of a project which most frequently fails, and that we view software as a tool for using hardware, we actively seek to minimize the amount and importance of software in each project.

ICIMACS is the computer and software system that has been developed to address our instrumentation needs.

We take the construction of 5 major instruments with successful use on 9 different telescopes at 5 different observatories to be strong evidence of the success of our approach.

2. COMPUTER ARCHITECTURE

The ICIMACS computer architecture is a peer-to-peer network of PC’s and Unix machines intercommunicating with either RS232 links or ethernet and transferring data through a dedicated high-speed SCSI bus. Each machine in the network can be operated either autonomously from its keyboard, or once connections are established, in synchronization with other machines. The entire system can be operated with no loss of functionality from any machine’s keyboard, from a terminal emulator outside the network, or from a more complex graphical interface, such as our Unix based “Prospero” user interface program. A telnet client session running on machines with network adaptors provides remote users with instrument control via the internet.

3. COMMAND NETWORK

A simple network protocol allows up to 256 machines on the ICIMACS network at a time, making for a huge number of possible configurations. The interconnections between machines are sensed dynamically as each machine boots up, and routing of messages between machines is handled automatically by using a simple messaging prefix of five ASCII characters that provide all the routing information for each message. All messages are in English ASCII to ease readability by carbon-based life forms.
4. DATA CHANNEL

The dedicated high-speed data channel is a series of one-way, point-to-point SCSI busses between an originating machine ("upstream") and a destination machine ("downstream"). Two unformatted SCSI hard drives on each bus are shared by the upstream and downstream machines to provide data buffering as well as a data cache deep enough for an entire night's images. While the upstream machine spools raw image data to one disk, the other disk can be read simultaneously by the downstream machine to make full use of the 10 Mb/sec bandwidth of the SCSI-2 bus. When the downstream machine signals that it has finished processing the images from the read disk, the disks are swapped and the process continues with the new disks. Buffering the bus in this way provides deep data caching, so that bottlenecks in one section of the data channel do not slow down data acquisition in the instrument computer. In addition, data acquisition speed can be increased by off loading parts of the image data manipulation to downstream machines.

5. DATA TRANSFER PERFORMANCE

Three aspects of ICIMACS lead to data transfer rates that are nearly transparent to the observer. The 10 Mbyte/sec SCSI-2 speed we currently employ could in principal transfer a MOSAIC image in 0.1 second. However the disk density and rotation rate limit the sustained transfer rate to about one-third this rate. The use of disks with a very simple format and data writes outside the operating system insure that most of the peak data transfer rate is available. The use of two disks, ping-pongning between a write-disk and a read-disk insures that the throughput is not limited by the time it would take to reposition the heads from the read position to the write position and back again. The result is that, despite the fact that a MOSAIC image is written three times and read twice, it takes only 1.5 seconds from the time a read is complete until an image is available for analysis on the Sparc-station. We currently spend about 1.5 seconds reading the MOSAIC detector which means that data acquisition never waits for data transfer. In fact, since there are up to three images in the pipeline at any one time we could read the array three times faster and still not have the computer system delaying the observing. Recent SCSI standards have been adopted with speeds as high as 80 Mb/sec and there several schemes, all using standard hardware, that could dramatically increase the throughput. No changes to the software or hardware architecture would be necessary to take advantage of this higher transfer speed.

6. ICIMACS CONFIGURATIONS

The ICIMACS flexible network architecture allows the specific needs of each instrument to be addressed. The configuration used by MOSAIC is full featured in terms of speed and capabilities, but an ICIMACS system capable of acquiring and writing image data files requires only an Instrument Computer (IC). Features are added and/or data transfer speed is increased by additional machines.

Instrument Computer

The Instrument Computer (IC) is a PC compatible computer that is responsible for data acquisition and communication with the telescope focus. The IC contains the ISL sequencer which produces the digital pattern to control the detector, receives imaging data from the telescope focus, and is the control-room end of the communications link to the telescope focus. Detector control is done through a sequencer “map”, a short data file which contains the digital pattern necessary to clock the detector, sample and digitize the data, and transfer it to the IC memory. Once the sequencer map is begun, the IC is free to perform its real-time functions such as de-lace the data from multiple amplifiers into a viewable image, display the data on its real-time display, perform co-adds of multiple samples, create the FITS standard header, and transfer the image data through the SCSI bus, either as a DOS file or in raw form, to be further processed by other machines.

Head Electronics

The Head Electronics (HE) contains all the electronics connected to the detector, a signal chain to process and digitize the data from the detector, a shutter controller, an LED drive circuit for pre-flashing or calibration, and 3 UARTS to allow the IC to communicate with other devices at the telescope focus. The HE and the IC communicate via a 120 MHZ full duplex fiber optics...
Instrument Electronics

The Instrument Electronics (IE) contains the electronics to control the mechanisms in an instrument, and a single board PC compatible computer. The IE computer is responsible for all mechanism motions. The IE communicates with the HE, and in turn with the IC, through a RS232 serial connection using simple English ASCII commands (e.g. FILTER 2), and performs motor control through a simple 12 wire interface with the other boards in the IE.

Workstation Interface Computer

The Workstation Interface Computer (WC) is a PC compatible computer. The WC’s purpose is to reduce demands on the IC during data acquisition. It normally performs the conversion of raw image data from the IC into FITS standard data. It contains a network card to provide a telnet client connection over the internet, and in some installations provides the interface to the telescope controller.

Caliban Program

The Caliban Program (CB) is a program running on a workstation (Sparc station or LINUX) that transfers the data from the SCSI disks on the bus between the WC and the Sparc station to Sparc station file system.

User Interface Programs Ariel and Prospero

Although not strictly a part of ICIMACS, Ariel and Prospero were designed and written by one of us (Pogge) to interface to the ICIMACS system. They provide an interactive, command-driven user interface, at-a-glance status info, a full-featured scripting language, on-line help and a tutorial, modeled on the Lick Observatory VISTA image processing program.

Other users at Michigan State University and Wise Observatory are in the process of writing their own user interfaces for their ICIMACS systems. The peer-to-peer network architecture and simple protocol used by ICIMACS makes the construction of a custom interface straightforward even when interfacing to LINUX and Windows 95.

7. ICIMACS Network Protocol

All ICIMACS messages take the form:

```
address_header message
```
terminated by a carriage return (ASCII 13).

The `address_header` gives the sender and addressee for each message in the form `XX>YY`, where `XX` is a unique two-character abbreviation for the sender, and `YY` is the unique two-character abbreviation for the addressee.

`message` is the message body. Its format depends on whether it is a command or status message.

The format for a command message body is:

```
keyword [keyword] [value [value ... value]]
```

The format for a status message body is:

```
message_type: message_text
```

`message_type` identifies the general meaning of the message, and can be of the following types:

- **STATUS**
  an informational message
- **DONE**
  a confirmation that a requested action has completed
WARNING
an unexpected result has occurred, but the action requested is continuing

ERROR
an error has occurred, and the requested action is being terminated

FATAL
a serious error has occurred which precludes taking or saving data. Usually caused by a hardware problem which requires user intervention to correct.

Note the required colon following the message type in a status message body.

The message_text can be either an unstructured text message, or a more formal, easily parsed message of the form

\text{keyword}=value [\text{keyword}=value [\text{keyword}=value \text{keyword}=value]], or any combination of the two.

The architecture of ICIMACS allows for a variety of configurations. Shown in figure 1 is the arrangement used on ONIS/TIFKAM/MOSAIC now in use at KPNO and MDM. The arrangement for OSIRIS while in use both at Lowell observatory and at CTIO is very similar. The configuration used for ANDICAM has two ICs and two HEs connected by SCSI busses to a single WC. On the other extreme it is possible to collect data with nothing more than an IC.

8. Conclusion

ICIMACS, based on off-the-shelf hardware and straightforward software, has been shown by actual use to be an excellent data and control system for optical and near IR instruments. ICIMACS uses hardware, that because of its great commercial popularity, is undergoing rapid increases in performance and value. We believe ICIMACS will still be a good choice in the era of 8k$^2$ CCDs, 2k$^2$IR arrays, and beyond.

9. Acknowledgment

We wish to thank the University Program at Altera Corporation for their continuing support. Their electronically programmable logic devices and development software have played a key role in the development of the ISL instrumentation systems.

10. Reference