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Control system architecture for mid-infrared cameras: from TIRCAM2 to IRAIT

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Abstract. TIRCAM2 is the upgraded version of the Tirgo (Telscopio Infrarosso del Gornergrat) mid-InfraRed CAMera (TIRCAM). The upgrading has been jointly carried out at the Astronomical Observatory of Torino (OATo) (Italy), working at the electronic and acquisition system design and construction, and at Institute for the Space Astrophysics of CNR (IAS), in charge of the cryogenic and optical system reconfiguration. The instrument has been endowed with the Rockwell 128x128 Si:As blocked-impurity-band (BIB) hybrid array. A new acquisition system has been designed and it results in a modular multi processor architecture based on TMS320C40 Digital Signal Processors. In perspective of the Italian Robotic Antarctic Infrared Telscope (IRAIT) and its IR-facility, the control system has been revised both on hardware and software components to fulfill the IRAIT standard control framework.

Key words. IR Astronomy – Focal Plane Array – Astronomical Instrumentation

1. Introduction

TIRCAM (Persi et al. 1994) is the mid-infrared camera developed between 1992 and 1994 to operate at TIRGO, employing the Hughes 10x64 photo-conductive array. The camera has been upgraded with the Rockwell high flux Si:As, 128x128 pixel BIB focal plane array (FPA), identified as HF-21, suited for the high background condition typical of the ground based applications; table 1 summarizes the relevant characteristics of the detector.

The detector is assembled on a Molybdenum plate, glued on a ceramic support hosting the electrical connections. Low resistance gold bondings connect the chip carrier pads to the printed circuit paths. All the detector signals are made available through a reliable flat cable ending with two miniaturized connectors. The mounting combines robustness and reliability. The drawback is the high

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thermal inertia of the mounting, that in turn implies long time for reaching 5 ^{o}K thermal equilibrium and slight thermal instability during operations.

To correctly operate the new detector and provide all the operating modes useful for IR ground based observations, an innovative controller has been devised; section 2 describes the hardware and the software of the control system.

In order to use the extended sensitivity up to 28 μm of the Rockwell detector, as well as to match the pixel size, a new optical system, based on a purely reflecting components, is under development at IAS laboratory.

The camera currently uses the optics of the previous configuration, which includes lenses, baffles, filters, heater and temperature sensors on the 8-inch oxygen-free copper base plate of the dewar. The optical scheme consists of relay optics made of two ZnSe lenses and a Lyot stop, and was designed for the 1.5m diameter, f/20 TIRGO telescope. It produces a magnification of 1.49 and a plate scale of 10.25 arcsec/mm, i.e. 0.84 arcsec/pixel on the Rockwell array with the Airy pattern covering 4x4 pixels at 10 μm. The exit pupil at the focal plane has a diameter of 7.68 mm, less than the total area of the detetector (9.6x9.6 mm). This produces a vignetting of about 10 pixels at detector edges. Such a limitation, acceptable for the preliminary set-up of the instrument, will be removed by the new reflecting optics. The filter system is made of five OCLI (Optical Coating Laboratories Industries) filters, 10% bandwidth, with effective wavelengths at 8.8, 9.8, 10.3, 11.7 and 12.5 μm, and a circular variable filter (CVF) covering the range 8-14 μm with 3% resolution. They are assembled in a circular filter wheel controlled by a step motor.

Optics, filter wheel and detector are accommodated inside a 2.8 liter liquid-He cooled cryostat fabricated by Infrared Lab, Tucson(Arizona); by a fine tuning of the thermal contact between the dewar plate and the array carrier, the working temperature of the detectors is fixed to 5 ^{o}K. We foresee to endow the equipment with a modern closed cycle cooler.

Although the camera has been refurbished to operate at a conventional telescope as TIRGO, some features meet the requirements for a similar observing facility planned for IRAIT. At some extend, TIRCAM upgrading has also been carried out to check scientific and technical operating modes to be implemented on the IRAIT camera: the Rockwell detector and the optimized incoming optics offer the opportunity to exploit the atmospheric windows beyond the 20μm, accessible on the Antarctic plateau; closed cycle cooler based dewar and remote controlled electronics are, at least partially, compliant to remotely and robotic operated equipment as required by the Antarctic environment. The experience acquired in building and operating TIRCAM and TIRCAM2 has been used to design the electronics for the IRAIT camera whose control system is described in some detail in section 3.

2. TIRCAM Control System

The control and read-out requirements for thermal IR arrays are for aggregate data rates up to several Megapixel per second from large number of channels, even for detectors not so large as the ones used in visible wavelength (CCD) and IR array for the near IR regime below 2.5 μm.

High background environment produces so much flux that thermal IR array saturates on a time scale of few milliseconds. Still, the sky background fluctuates at rate of few hertz and overcomes the signal from stars; in such a condition, the detection of scientific target is possible only sampling alternatively sky and source signal, i.e. by chopping technique, which increases the number of data throughput.

Handling a modern astronomical focal plane array, sensitive at wavelength longer than 5 μm, providing large well capacity and large number of readout channels, requires a control system featuring high performance in terms of read-out speed, dy-

Table 1. Rockwell Array features

Rockwell 128x128 pixels Si:As BIB Focal Plane Array	
Pixel Pitch	75μm
Spectral Response	2-28 μm
Q.E.	0.7
Well Capacity	$2.10^8 e^-$
n. outputs	16
Frame rate	$< 4000/sec$
Readout Noise	~ 1300
Output Signal	2.5 Volt
Readout Mode	Destructive
Sampling Technique	Single read

Table 2. TIRCAM2 Acquisition system performances

System		Detector	
Timing by 16 bit counters:		Read Time allowed:	
Frame time	$> 360\mu$m	Frame rate	< 4000/s
Pixel Time Resolution	$160ns$	Single Output rate	$< 4x10^6$ px/s
Frame co-adding capacity	< 128000		
System Transfer Gain:		Readout Noise:	
	153 μV/ADU	@ zilch flux	172 μV
	1485 e^-/ADU		(1720 e^-)
A/D toggle noise:	0.7 ADU		
Preamp input referred noise:	110 μV	@ $4x10^{14} ph/s/cm^2$	330 μV
	(1050 e^-)		(3300 e^-)

namic range and real time data processing capabilities.

The TIRCAM2 controller is designed to satisfy all these requirements, and, though it is tailored for the detector in use, its modular architecture, both hardware and software, can be easily upgraded to different applications.

The controller is split in two blocks and employs commercial components and custom parts. The first block consists of a custom circuit with 16 low noise, high bandwidth pre-amplifying channels, matching the detector video signals to the dynamic range of the Analog-Digital(AD) converters. The industrial PC rack houses the acquisition cards and the custom bias-clock generator in the ISA bus branch of the back-plane. CPU board, the video interface and the Ethernet card are allocated on the PCI bus.

Both units, when the camera is installed at the telescope, are located very close to the dewar; a box driver is employed to place the user input-output devices (keyboard, video and mouse) 30 meter away.

Digital control, AD conversion and numerical processing are in charge of three ISA compatible PC cards, based on Texas Instrument TMS320C44 Digital Signal Processor (DSP) and commercialized as PC44 by Innovative Integration, CA. Each PC44 carries two mezzanine modules (ACQ44) complying with the TIM44 standard. Each ACQ44 implements three 14 bit 3 MHz A/D converters and is endowed with one C44 DPS.

A custom card plugged into a ISA slot generates the detector's biases and produces the appropriate levels for detector's clocks; it also buffers all control signals for the acquisition system, as trigger for A/D converters, wobbling mirror and filter wheel motor.

The relevant system features are summarized in table 2.

Overall, the acquisition system results in a multi-processor environment including nine DSPs, each executing optimized C algorithms for the specific tasks to be performed: six DPSs are involved in capturing and pre-processing data, performing frame co-adding and statistic analysis; one DSP acts as a sequencer, producing the digital timings for the needs of the whole acquisition process, that is A-D conversion trigger, chopper control, filter wheel controls, and clocks for the array. Two other DSPs are available to perform further on-line data analysis oriented, for instance, to guiding purpose or image reconstruction, i.e. shift and add.

The camera software interface has been designed to meet the parallel hardware architecture. It consists of a multi-thread Windows like user interface, written by Visual C++ and executed in Win NT OS. The main thread handles the graphic interface and spawns ancillary threads which monitor the DSPs' status, gather data from DSPs and passe them to the main thread for further on line processing and display.
The graphical user interface (GUI) is a collections of coordinating panels, which furnish user-friendly tools to set up the instrument.

Different observing techniques are allowed: staring, beam-switching, chopping and chopping+nodding; all of the observing modes can be programmed and accomplished automatically. Each mode can be sorted in a sequence of equal integration cycle inclusive of periodic displays of the field being observed and data storing into file. Observing modes which require calibrated telescope movements, e.g. nodding and beam-switch, are supported by a dedicated interface to telescope pointing system based on serial link RS232 compliant with the TIRGO standard message protocol. In real time, the program produces a quick look of the frames collected after preliminary pre-processing suited for the programmed observing mode. Data storing, in a standard FITS file, can take place both on the local disk and on a remote computer by the Ethernet link.

3. The IRAIT mid-IR camera

The IRAIT project (Tosti et al. 1997) is aimed at preparing a permanent observatory at Dome C, a site located at 3200 height on the Antarctic plateau. To exploit the high-quality low-sky-background conditions offered by the site in spectral regions beyond 20μm, the Mid-IR camera of IRAIT is designed to operate with a Si:As detector array sensitivity in the range 5-28 μm, or a Si:Sb array for the extended range 5-40 μm. Antarctic environment requires robotic and remotely controlled operations for the telescope and its instrumentation and imposes accurate insulation for all the equipment not working in warm rooms. The telescope control system is under development and is designed as a distributed architecture based on object oriented control software. Automatic operations are based on ad hoc script language, the Telescope Control Macro Language (TCML) (Tosti et al. 1995).

The camera sub-system, sketched in figure 1, complies with this standard. The detector is housed into a cryostat equipped with a closed cycle cooler suited for very low temperature (4-6 ^{o}K) cooling. So far, expertize in this field is available in countries outside Europe: leading firms providing well qualified cryogenic equipment are located in US or Japan. In order to promote European technology in this strategic field of low temperature system, Italian or Europen facilities will be invested with study and construction of the IRAIT camera cryostat.

The controller is designed as split in two units. The front-end unit consists in a small PC rack configured as a PCI embedded system, which houses updated version of DSP based acquisition boards and the system CPU for bus arbitration and system initialization. Custom pre-amplifiers and fully programmable bias-clock generator inter-

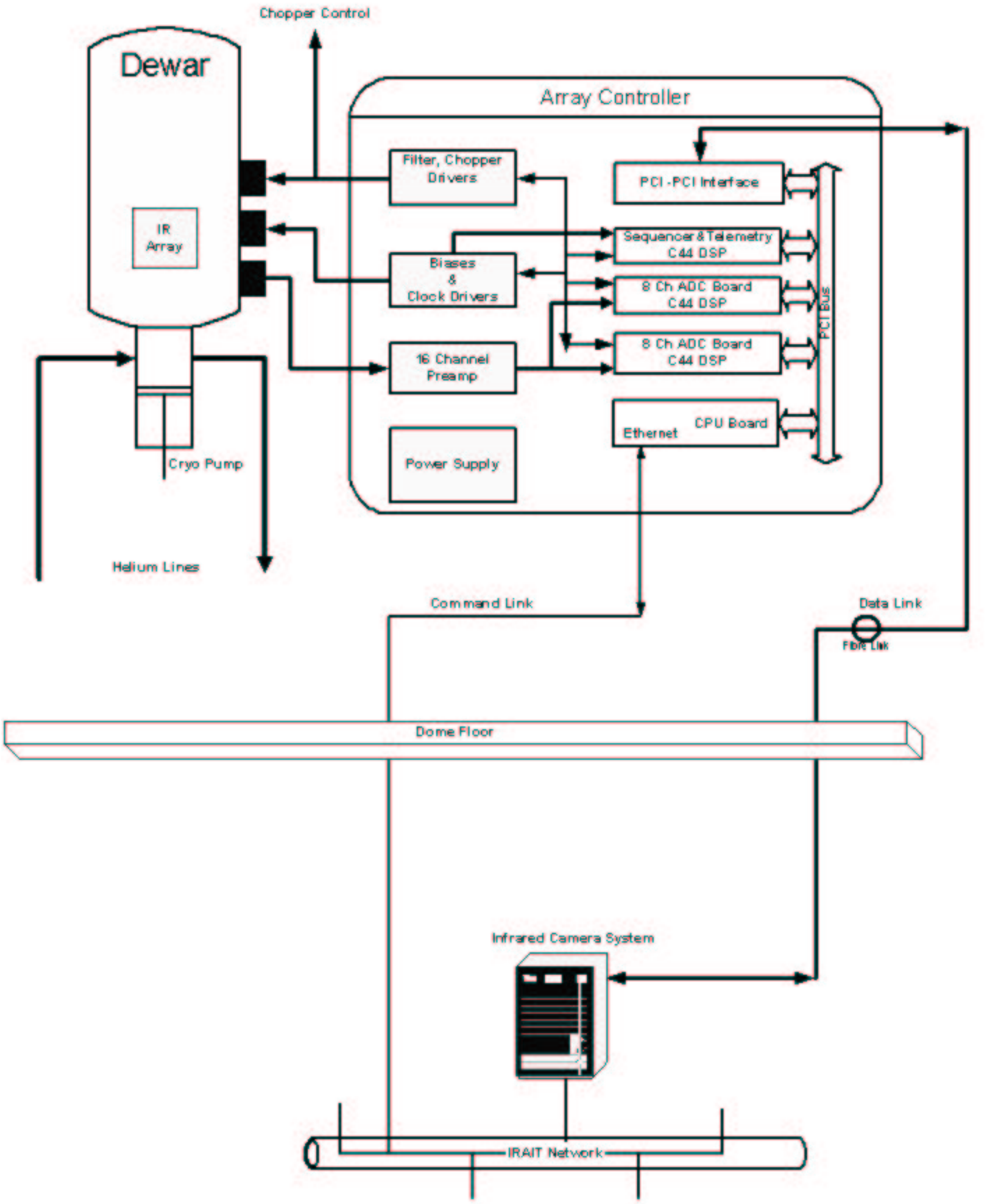

Fig. 1. IRAIT camera architecture.

face the detector to acquisition channels; the critical bias values are monitored by a dedicated telemetry channel. The unit will be placed close to the cryostat at the bottom of the telescope and then it will be insulated to operate at low ambient temperature. A remote host PC runs the software instrument interface, performs quick-look, data logging and further online analysis on both image and telemetry data, handling alarm signals whenever required. The two units are bridged by a PCI-PCI interface on optical fiber link devoted to data transfer, which ensures high bandwidth and long distance connectivity. Both units are connected to the IRAIT local area network, through which the remote control is implemented.

4. Conclusion

TIRCAM2 started operating at TIRGO in winter 2000-2001. The first astronomical results (Persi et al. 2001) demonstrate performances comparable to the major operating mid-IR cameras when properly scaled by the telescope diameter, in spite of an unexpected spurious noise (see Persi paper in these proceedings). The noise source has been identified and partially removed during recent laboratory test and we expect to have an improvement in performances by at least a factor 4 in the next runs.

The IRAIT camera design is underway; many commercial parts are already acquired and assembled, the custom circuits, derived by TIRCAM experience and with added functionality compatible with the Antarctic constraint, are designed and their construction will start in the next months. The software of TIRCAM will be ported on the IRAIT camera platform.

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