A REAL-TIME SPECKLE FACILITY FOR THE TELESCOPIO NAZIONALE GALILEO

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Abstract. Speckle imaging should in principle achieve diffraction-limited images of astronomical objects observed through the blurring effect of the atmospherical turbulence. This paper presents a speckle camera for the Telescopio Nazionale Galileo (TNG), which provides in realtime the auto-correlation of the object shape. The magnification system, the acquisition camera, and the choice of filters are briefly described. The hardware architecture, based upon three 166-MHz CPUs operating within a PCI Bus standard, is also described

1. Introduction

Speckle imaging is a technique (Labeyrie 1970) that allows one to obtain full diffraction-limited performance on images blurred by atmospheric perturbation, provided the focal plane image is analyzed grouping the collected photons into time bins not larger than the mean speckle lifetime (typically of the order of 10 ms at visible wavelengths).

Speckle imaging is, essentially, a post-processing technique on a huge amount of data, which have to be stored on-line. With today's technology, using relatively low-cost hardware, real-time data reduction can be achieved, retrieving only the autocorrelation of the shape of the observed celestial object.

In the adaptive optics system module of the Telescopio Nazionale Galileo (AdOpt@TNG) an independent speckle facility is planned. The TV signal generated by an intensified CCD camera is fed to three different frame grabbers plugged into three industrial, single-board CPUs that digitize, rebin, Fourier transform, and accumulate the obtained Fourier pair of the focal plane image.

After a convenient accumulation time, the three sets of images are co-added in one of the processors and fed to the whole control system. Triggering the frame grabbers, by a dedicated multiplexing device, allows one to relax the time needed to perform real-time processing and to reach a full 25 frames per second autocorrelation function accumulation.

With this low-cost approach, diffraction-limited performances can be achieved even on nearly photon-limited stellar objects.

2. The Magnification System, the Filter Wheel, and the Acquisition Camera

In order to allow full diffraction-limited resolution, the focal plane must be sampled with an appropriate scale by matching the Nyquist criterion in order to have at least four pixels covering the size of the Airy disk at the focus. Because the beam fed into the speckle camera has a focal ratio of F/32 (due to the magnification of a factor 3 of the AdOpt@TNG), the Airy disk, which has an angular dimension of 0.031" at a wavelength of 550 nm, shows a diameter of 18 μm. We want to digitize a subframe with a resolution of 128 $\times$ 128 pixels; in this mode one pixel has a projected dimension on the photocathode of 45 μm, so a magnification of $\approx$10 is required.

Another option of no magnification (1:1) is chosen because we want to use the acquisition camera of the speckle module to control the correction performances of the AdOpt@TNG without using the scientific cameras.

Two lens objectives are selected for the two options: one of 105 mm focal length (1:1 imaging) and one of 35 mm focal length (10$\times$ magnification). These objectives are mounted in a fixed position on a movable bench. The acquisition camera is a microchannel plate double stage intensified S-25 photocathode coupled to a CCD with an optical fiber bundle. The useful wavelength range is between 360 and 850 nm with a maximum efficiency at 550 nm.

The main control unit could select via digital command the exposure

TABLE 1. The filters adopted in the TNG speckle camera

$\lambda_0[nm]$	$\Delta\lambda[nm]$	name	notes
475	30	b	colored glass filter [ORIEL 51690]
547	30	y	long-pass [ORIEL 51300] and band pass [ORIEL 51970] filters coupled
550	10	C_2	Swan C_2 absorption band
570	10	$C_{2\ cont}$	continuum adjacent to the C_2 band
650	10	ZrO	ZrO absorption band
670	10	TiO	TiO absorption band
660	10	H_α and [NII]	emission lines
580	100	wide-band	this transmission profile is obtained by cutting the camera sensitivity at longer wavelength by means of a short-pass filter [ORIEL 57377, 50%]

time of the acquisition camera as well as the choice of the filters and the magnification desired.

3. Bandwidth Selection

After the objectives, a filter wheel (eight positions) provides the bandwidth selection for different scientific targets. Filter characteristics are shown in Table 1 along with their effective transmittance (see Fig. 1).

The two filters b and y are intended to match the correspondent Strömgren bands. The y filter is composed of a sandwich of (a) a long-pass filter of 50% transmittance at 530 nm, and (b) a band-pass filter with central wavelength of 510 nm and a FWHM bandwidth of 100 nm. The short-pass filter, for general purpose faint objects applications, has a cut-off, at 50%, of 595 nm. The others filters are used for morphological studies of cool stars. The resolution of a large optical telescope is high enough to resolve the stellar disk of nearby giant/supergiant stars (Balega *et al.* 1982, Welter & Worden 1980a, Christou & Worden 1980b), as well as to reveal photospheric asymmetries and surface inhomogeneities (Lynds *et al.* 1976a), and to study the dependence of diameters on wavelength (Bonneau & Labeyrie 1973, Lynds *et al.* 1976ab).

Weigelt *et al.* (1996) show that there is a strong difference in the diameter measured in the TiO absorption band and the diameter measured in the adjacent continuum in the M-type Mira variables. To optimize investigation of cool stars of different chemical abundances, we have selected a set of four filters (marked C_2, $C_{2\ cont}$, TiO, and ZrO in the table) in such a way that the filter for one molecular band is useful for measuring the adjacent continuum in another molecular band.

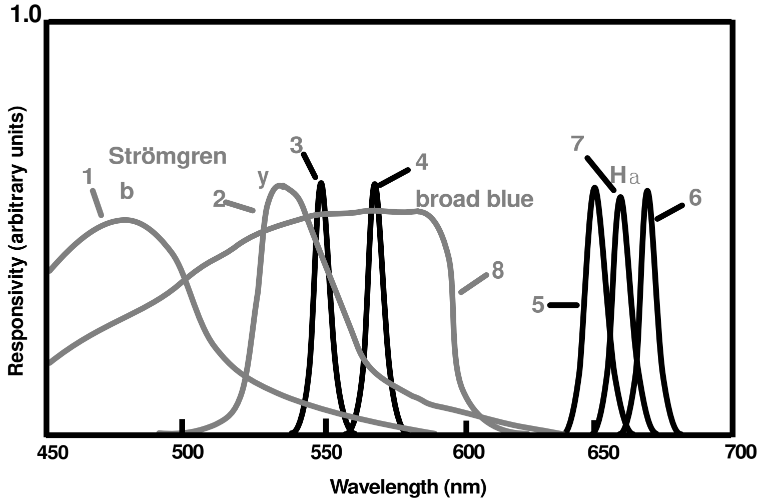

Figure 1. Effective transmittance of the selected filters.

4. Frames Acquisition and Processing

The architecture of the acquisition system and data processing is shown in Fig. 2.

The video signal of the camera (CCIR, a standard B&W at 25 frames/s) is sent to many different devices. One is the vertical synchronism extractor that detects the beginning of each frame and feeds the impulse to a sequencer that sequentially distributes an operating "green light" to the three frame grabbers; when a frame grabber board receives such a signal, a frame digitization occurs. The signal is also sent directly to the three frame grabbers. Optionally, the capability to record on a magnetic tape a movie of the astronomical observed target in order to apply further image processing techniques may be implemented (Liu & Lohmann 1973, Bates & Cady 1980, Knox & Thompson 1974, Weigelt 1977).

Each frame grabber could acquire at 25 frames/second a full 8-bit 754×480 image. Anyway, to allow real-time autocorrelation accumulation at the full frame rate the number and size of images must be conveniently relaxed. As mentioned above, the digitizing boards are triggered in such a way that they acquire just one image out of three: the grabbing sequence for the first board becomes #1,#4,#7..., for the second board #2,#5,#8..., while for the last board it is #3,#6,#9,....

A 128×128 sub-part of a frozen image is stored in the RAM of the respective CPU board via PCI Bus with a transfer rate of 132 Mbytes/second (much higher with respect to the traditional ISA Bus).

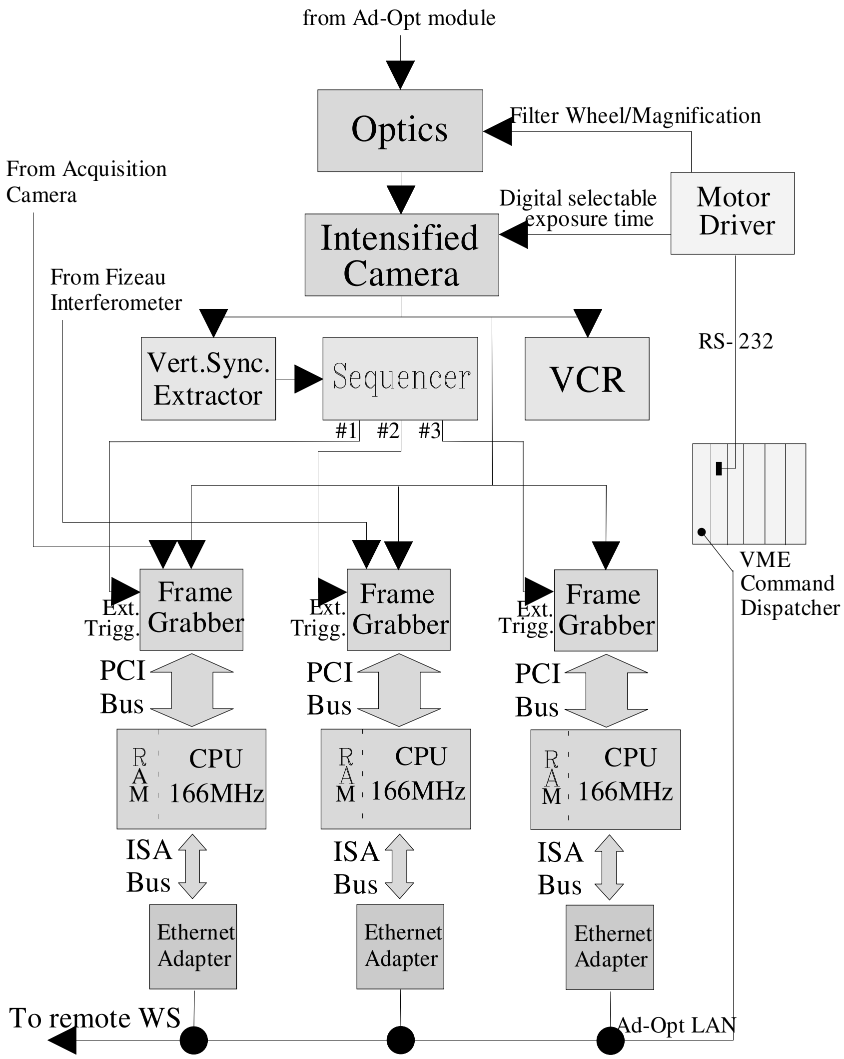

Figure 2. Architecture of the system.

A fast CPU (clocked at 166 MHz) provides the calculation of the power spectrum (namely the squared module of the Fourier transform) of the stored image and the sum between it and the previous bidimensional power spectrum obtained in the same way; the typical benchmark of this CPU to compute a 128×128 spectrum and to store the global sum into the memory amounts to roughly 77 msec. At the end of the process each CPU board transfers its accumulated power spectrum via an Ethernet link to the master PC (one of the three) so that it can be added to the other two.

The whole process has to be performed both for the astronomical target and an unresolved source in order to filter out the power spectrum of the atmospherical turbulence via the experimental measurement of the speckle transfer function (STF).

The autocorrelation function (ACF) of the angular brightness distribution of the astronomical target is retrieved from the inverse Fourier transform by dividing the accumulated data with the STF.

All the functions of the speckle camera are driven by a remote workstation via the AdOpt@TNG local area network.

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