A CCD Camera for Astrometric Observations

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Abstract

Small-field astrometry has taken advantage of the progress achieved by the CCD technology, especially in the field of quantum efficiency enhancement and of the production of very large devices.

Furthermore the improvement in the design and manufacturing of scientific CCD controllers has greatly enhanced the overall performances of CCD systems. State of the art controllers are able to operate a wide variety of CCDs and more importantly they are able to readout simultaneously from two or four outputs so as to reduce the time to read the whole image.

As a consequence of that, CCD astrometric observations have increased both in quantity and in quality.

We are currently designing a CCD camera system to be placed at the 61 cm Schmidt telescope of the Catania Astrophysical Observatory on Mount Etna. The camera will perform astrometric observations and wide band photometric observations of minor objects of the solar system and in particular of near earth objects (NEO).

The CCD detector will be operated using the CCD controller developed for the italian national telescope "Galileo".

Here we report on the preliminary design and on the expected performances of the system.

Keywords: Small-field Astrometry with CCD, wide-band photometry of near earth objects.

1. Introduction

The progress achieved in CCD technology has contributed positively to astrometric observations. In fact astrometry and photometry of minor objects of the solar system increased in quantity and in quality by using large-area CCDs as focal plane detectors.

The use of CCDs in astrometry is a consequence of their properties, mainly the good quantum efficiency, the wide dynamical range and the linearity of response. The main problem affecting astrometric observations with CCD is that the individual pixels respond differently to a uniform illumination. A calibration in terms of thermal noise (hot spots) and in terms of uniformity (traps and dark spots) is required. The method of taking the average of several exposures of a calibrated uniform light source, called "flat field normalization", is a good approach but is not fully satisfactory. Incorrect calibration of some areas of a CCD would change the true light distribution, inducing errors in the determination of the position of the centroid of the observed source.

Big efforts have been done in improving scientific CCD controllers, in order to operate a wide variety of CCDs. State of the art controllers have the ability to readout simultaneously from two or four output amplifiers, speeding up the readout of the whole image. They allow, also, different readout modes by fast or slow shifting of the charge towards one of the CCD outputs. In particular, for astrometric observations, a very satisfactory technique, known as *drift and scan* mode, consists of shifting the collected charge in the direction of diurnal motion of stars while keeping fixed the telescope.

At the Catania Astrophysical Observatory we are currently designing a CCD camera system for astrometric observations and for wide-band photometric observations of minor objects of the solar system. The camera will be placed at primary focus of the 61 cm Schmidt telescope at Serra La Nave on Mount Etna.

To operate the focal-plane detector we will use a CCD controller of the same type developed for the italian national telescope "Galileo" (Bortoletto et al. 1996).

2. The optics

The optics feeding the CCD includes the 61 cm primary mirror and the 41 cm corrector lens ($f/3$) of the Schmidt telescope, a set of wide band filters, and a field-flattener (see Figure 1).

The focal length of the instrument is 1220 mm and the plate scale is $169''$/mm.

The adopted optical configuration will produce images of pointlike objects with a FWHM better than $1''$ over a field of view (FOV) of 1° in diameter. Thus the atmospheric turbulence, typically expected to be between $2''$ and $3''$, will set the final size of the point spread function (PSF). The focal plane is flat making the mounting of the CCD straightforward.

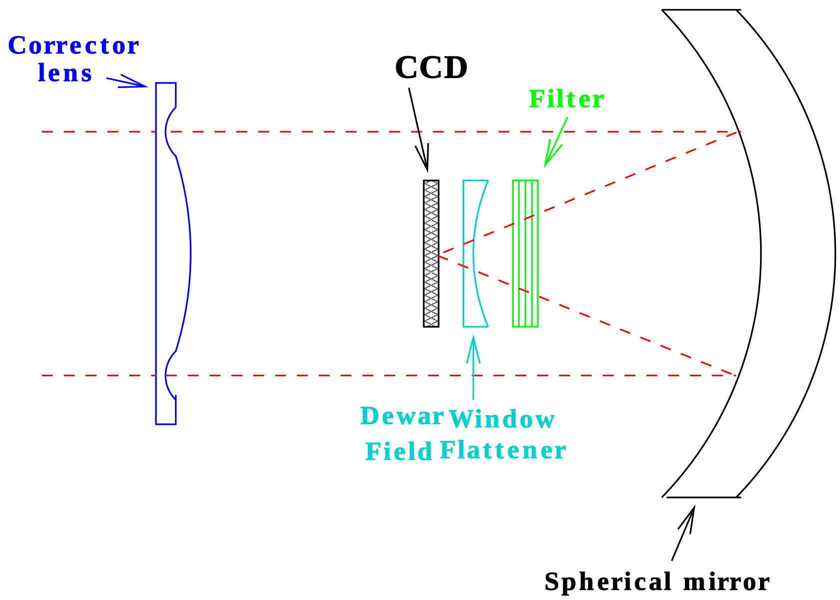

Figure 1 - The optical layout of the telescope and camera

Adjustments of the telescope structure and driving engines are in progress to allow the instrument to work in a drift-scanning mode.

3. The CCD camera

Due to the structure of the telescope, the most important requirement the CCD camera must fulfill is the compactness. The main components of the camera will be the CCD housing, a field flattener, a filter holder and a shutter.

A preliminary version of the CCD housing is shown in figure 2. It will contain the CCD itself, the CCD printed circuit board (PCB), the thermoelectric cooler (TEC) and the heat exchanger (also shown in the figure). The field flattener will be used as the window of the CCD housing.

Due to the bad accessibility of the focal plane of the telescope, the cooling of the CCD through liquid nitrogen is unfeasible. The adopted solution is based on the use of a multistage TEC module, a solid state device that utilizes the Peltier effect to pump heat out of the CCD (see e.g. Petrick, 1987). These devices can easily cool the CCD to temperatures between $-40°C$ and $-100°C$, depending on the TEC characteristics, the heat load of the detector, and the temperature of the hot side of the TEC. The removal of the heat is achieved through the coupling of the TEC hot side with a copper heat exchanger, thermally insulated from the

CCD housing, which has a fan on its final plate (see figure 2). The use of a TEC together with a Multi Pinned Phase (MPP) CCD will allow us to operate the CCD at relatively high temperatures ($\sim -60^{\circ}C$) still keeping the detector's dark current to very low levels (typical values 1 $e^{-}\ min^{-1} pixel^{-1}$).

Figure 2 - Left panel: outside view of the preliminary version of the CCD housing, it is clearly visible the preamplifier box and the outside part of the cooling system. Right panel: inside view of the housing with the Peltier assembly.

The current choice CCD is a 2048×2048, $15\mu m$ pixel size, back-illuminated, three-edge-buttable, MPP device manufactured by SITe. We are also considering the possibility to use a front-illuminated, UV coated, 2048×2048, Kodak CCD with a pixel size of $9\mu m$.

The plate scale of the telescope is $169''$/mm, so the FOV of the CCD will be of $\sim 1^{\circ}.5$ and $\sim 0^{\circ}.9$, respectively, while the pixel size in arcseconds will be $2.5''$ in the first case and $1.5''$ (better PSF sampling) in the second one.

4. The CCD controller

The CCD controller that will be used to operate the detector is the same developed for the italian national telescope "Galileo". It is based essentially on transputers and Digital Signal Processing (DSP) modules. The transputer technology has been adopted to take advantage of the flexible networking and communication scheme provided by it, while, a dedicated DSP (Motorola 56001) was selected to generate fast and synchronous sequences.

The overall controller is made of two fundamental components: the host PC and the remote controller. The host PC has, installed inside, a special interface able to hold various transputer modules. Figure 3 shows the block diagram of the CCD controller. The remote controller consists of the preamplifier, the sequencer, that provides the logical signals, the analog board, that provides the biases, the clocks and the video processing. The last board is able to process and convert independently 4 video-channels in 16 bit data by using the correlated double sampling technique (ref). All the voltage levels are programmable and their values can be monitored by telemetry.

Furthermore the sequencer provides shutter and temperature controller handling. Eight temperatures are monitored and one of them will be controlled.

The performances of the controller, derived from preliminary tests, are summarized in the following table:

CCD Controller performances

	1 channel	4 channels
Pixel rate	50-100 kHz	50 kHz
Acquisition rate for a frame 2k $\times$ 2k	40-20 s	10 s
Readout noise	$< 1e^{-}\ rms$	$< 1e^{-}\ rms$

The CCD controller allows different readout modes:

1. full frame,
2. set of predefined boxes with fast skip of unwanted pixels,
3. binning on chip,
4. drift scan mode.

The first mode can be obtained reading from one, two or four corners.

The second mode allows to set in the image various interesting boxes (containing the objects of interest) and acquire data only from these. Thus it is possible to save time and mass memory.

The binning on chip is very useful for the photometry of very faint objects. In fact, using this mode is possible to pack the charge before reading it through the output amplifier, obtaining a pixel of 2×2 or bigger, affected by the read noise corresponding just to that of one pixel.

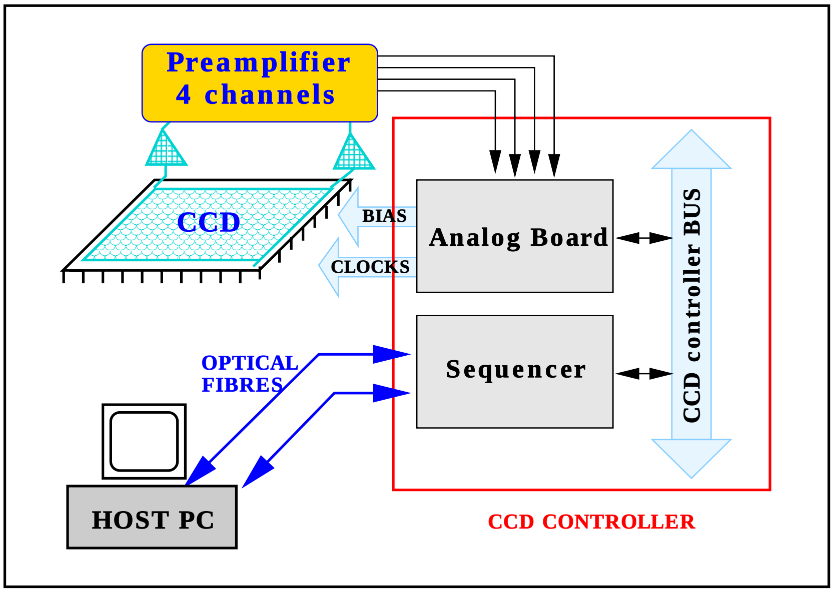

Figure 3 - Block diagram of the CCD controller

Finally, the scan mode consists of the following procedure:

a – the telescope is kept fixed;

b – the CCD is positioned in such a way that its columns are parallel to the diurnal motion of stars;

c – the charge is shifted in the CCD continuously at the same rate at which star images drift across the focal plane.

In this manner, while a star is in the field of view, it leaves a strip, and the exposure time is equal to the time of transit of the field. Eventually one gets an image whose width in declination corresponds to the width of the CCD, and it may scan in right ascension over, in principle, several hours. In addition to the possibility of observing stars in a long field in one direction, there is a second advantage: the charge is integrated along the column and consequently the pixel-to-pixel non-uniformities are smoothed out and also the flat-field normalization is not needed (see, for example, Mackay 1986).

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