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Performance evaluation of high-speed camera system for adaptive optics

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Abstract. Atmospheric turbulence distorts the incoming wavefront from the star light, thus severely limiting the resolution of the groundbased optical telescopes (Fried 1966). Adaptive optics is being implemented in all big telescopes to remove the distortion created by the atmosphere. In this paper, we are dealing with the selection and testing of three types of high-speed imaging systems, a crucial component for wavefront sensing.

1. Introduction

The new generation of 8 to 10 m class telescopes have impressive light-gathering capabilities, but without atmospheric compensation their resolution capabilities are the same as that of a 10 to 15 cm telescope. (Primmerman, 1991). Adaptive optics is a real-time atmospheric compensation technique that can be used to improve resolution. The essential sub-systems of adaptive optics are wavefront sensing, wavefront error computation and wavefront correction. We have developed a Shack-Hartmann lenslet array based wavefront sensor for use in adaptive optics. As the wavefront sensor needs a very high-speed camera systems, we have evaluated two of the high-speed camera system that we use for Speckle Interferometry observations. We have found some drawbacks of these systems and so we are integrating a high-speed imaging system based on the newly developed CMOS imager. We found that the architecture of CMOS imager is well suited for this kind of application.

2. Intensified Peltier cooled CCD

This camera is routinely used for speckle observations at Vainu Bappu Observatory (Saha et al. 1999). It has high speed image acquisition features with programmable integration times of a few milliseconds to seconds. The CCD used here is a EEV chip with 576 x 378 pixels. Because of the architecture of the CCD, even to read 10 by 10 pixels occupied by a single star, one has to read the whole device. This increases the reading time thus limiting the number of frames that can be read with these systems. Frame transfer devices that store the image on chip in other half of the chip improves the speed but reduces the imaging area by half. Theoretically, about 80 frames per second can be read from the CCD with a controller speed of 1 MHz. As we need a system which can capture at least 100 frames per second, this may just meet the speed requirement. But the camera software as supplied by the manufacturer is well suited for high-speed image captures that writes the data to the disk for later off-line processing. Extensive software modification is required if it is to be used for real-time control.

3. Low light level CCD (L3CCD)

This is a major breakthrough in the CCD sensor development. In an intensified CCD, a microchannel plate gives light amplification in the order of tens of thousands. In the L3CCD, the imaging area and readout registers are of conventional design but there is an extended section of gain register between normal serial shift register and the final detection node which is operated at a much higher voltage level (typically 40 to 50 V instead of nominal 10 V). This large voltage creates avalanche multiplication which thereby increases the number of electrons in the charge packets, thus producing gain. The advantage of L3CCD is that at low light levels, it can have single photon detection comparable to the intensified CCDs. As there is no MCP and the associated high voltage and also there is no coupling problem between MCP and the CCD, system integration problems are less and it can tolerate high light input without getting damaged. We have recently procured L3CCD based high-speed imaging system for speckle observations. This L3CCD is Peltier cooled to –65 deg C and with water circulation, it can reach –80 deg C. Hence, it gives a noise performance comparable to the liquid nitrogen (LN2) cooled cryostats. Architecture-wise, L3CCD is same as the regular CCD except the extra gain stage register, hence its high-speed operation is comparable to that of ICCD. Like other CCD, it has full frame, frame transfer and kinetic mode of operation. The major drawback is the software. In the kinetic mode, if the integration time is chosen as 10 milliseconds, it should be possible to collect about 100 frames per second, but the system gives only about five frames per second. As the source code is not available, we are unable to modify the software to acquire more number of frames.

4. CMOS imager

CMOS imager is the recent development in the image sensor field. It is a monolithic solid-state camera chip with random addressability and logarithmic response. Random addressing of pixels enables frame speeds in the order of thousands, satisfiying an important requirement of wavefront sensor. Thus it is possible to build a low cost wavefront sensor based on CMOS imager. We have designed and fabricated a Shack-Hartmann lenslet array based wavefront sensor with CMOS imager (Chinnappan 2001). If a 100 by

100 sub region of image is read, it gives about 100 frames per second. The acquisition software was developed by us. As there is no intensification of the incoming light source, this system can be used for bright sources only or else an image intensifier is to be attached in the front. We have procured a MCP manufactured by Bharat Electronics Ltd. and the same is being integrated with the CMOS imager.

5. Conclusion

We have evaluated two high speed imaging systems already available to us for their use in wavefront sensing for adaptive optics. We found that the conventional CCD architecture is not suitable for high-speed imaging. We also found that even though the time required to acquire one frame is in the order of a few milliseconds, there is large time interval to obtain the next frame thus effectively reducing the number of frames per second that can be obtained. The newly developed CMOS imager has random access capability which allows us to read the required region of interest at great speeds satisfying the important speed requirement. As the integration times are very low and the CMOS imager has no on-chip integration facility, faint stars cannot give much signal level. MCPs are to be integrated before the imager. We have integerated Shack-hartmann lenslet array with the CMOS imager to make a wavefront sensor and obtained data through the system. The performance of Shack-Hartmann lenslet array based wavefront sensor using the CMOS imager as detector is satisfactory and meets the important requirement of wavefront sensor for adaptive optics.

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