Setup of a commercial digital SLR, large area, triggerable CCD camera for optical laser-plasma diagnostics

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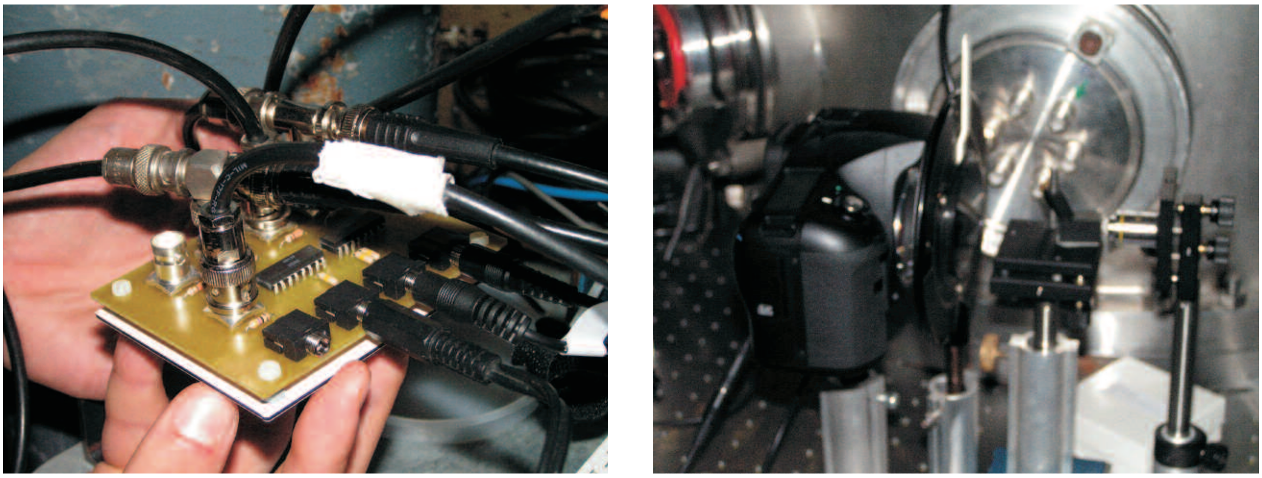

Figure 1. Left: four channels triggering PCB. Right: two Pentax cameras mounted in an experiment.

Introduction

CCD (or CMOS) detectors are currently widely used in a broad range of experimental configurations as the main tool for the detection of optical emission. In the field of laser-produced plasma physics, they are employed both for the plasma emission as well as for the diagnosis of laser beams. Today, all the major suppliers of laboratory instrumentation are able to provide compact CCD detectors with external triggering capability and USB or IEEE1394 (FireWire) interface at affordable costs. However, in spite of the ever reducing costs of the CCD chips, prices still exceed 1k€ for 8bit ADC cameras and rise up to some k€ for >10bit cameras, probably due to the limited size of the scientific instrumentation market. More important, only a few manufacturers are able to provide large area (25 mm or so) detectors for scientific purposes, with costs exceeding some tens of k€s. This is a major drawback, since in most cases in laser and plasma diagnostics a wide area detector would be preferred. On the other hand, as for the overall detector dynamic range, in some cases an 8bit ADC would be enough. These requirements are surprisingly fulfilled by commercial digital SLR (single lens reflex) cameras.

In this paper we report on the work carried out to study the feasibility of adapting commercial, low-cost (less than 1k€) SLR reflex cameras for optical diagnostics in the field of laser-plasma experimental physics.

Camera description and triggering system

Two different models by Pentax (a division of Hoya Co.) have been tested and successfully employed in some experiments, namely the Pentax K10D and the K100 super camera. Both cameras are equipped with a standard size (23.5×15.7 mm) CCD chip (with primary colours filters) and a 24bit (8bits/colour) ADC. The only differences are in the pixel number and size (3872×2592, 6×6 μm^2 size pixels in the K10D case and 3008×2008, 7.8 μm^2 size in the K100 super case). Both cameras provide an USB interface and they can be connected to an external monitor for optical alignment purposes. For their use in laser-plasma interaction experiments, a major difference between the two cameras lies in the presence of a strong IR filter (directly glued on the chip) in the K10D camera. While being of no or a minor concern for some applications, like, e.g., 2nd harmonic interferometry, this can be a major limitation in some cases. Finally, both cameras support SD memory cards for archiving the images and a raw, lossless data format.

In order to trigger the cameras, the jack input for the shot remote control has been used. After having identified the signal sequence needed for the trigger (which was the same for the two models), the internal delay (that is, the delay between the shot trigger and the shutter opening) has been measured by means of an ad hoc printed circuit board equipped with a set of 8 red LED which could be switched on in 256 different patterns with predefined time intervals. An internal delay of about 70 ms was estimated for the K10D, with a jitter of about 20 ms. The K100 super camera exhibits a greater internal delay, roughly double the one of the K10D. A 4-channel triggering PCB has been designed and assembled to trigger up to four Pentax cameras at the same time. The PCB is shown in figure 1 left: the four jack sockets are clearly visible on the front side of the PCB (providing the trigger sequence to the camera) as well as four BNC sockets for the trigger input (TTL signal). In fact, a 'pre-focus' signal is used by the internal autofocus system of the camera (not used for our purposes but still needed) and must be sent to the camera some hundreds ms before each shot. For this purpose, a further BNC socket is provided on the board, visible at the top of the PCB.

Dynamic range and spectral response

Some preliminary tests have been carried out in order to estimate the dynamic range and the spectral response of the CCD camera (in this Section we refer, in particular, to the K10D model).

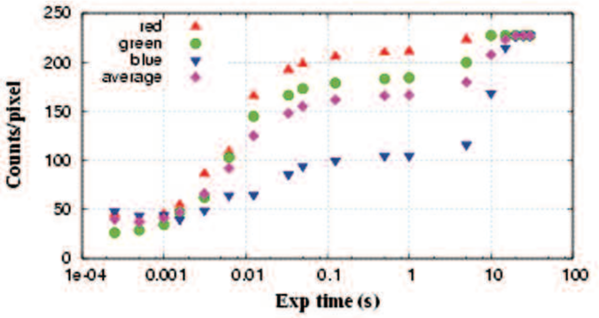

Figure 2. Results of test 1 on a Pentax K10D camera.

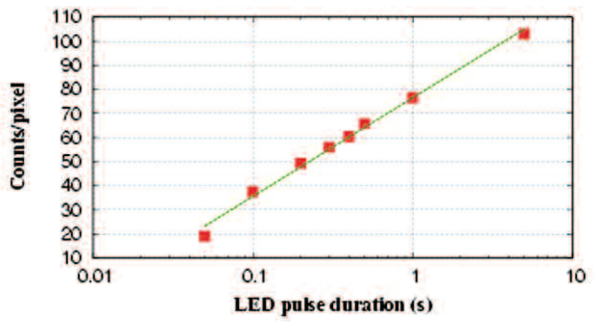

Figure 3. Results of test 2 on a Pentax K10D camera.

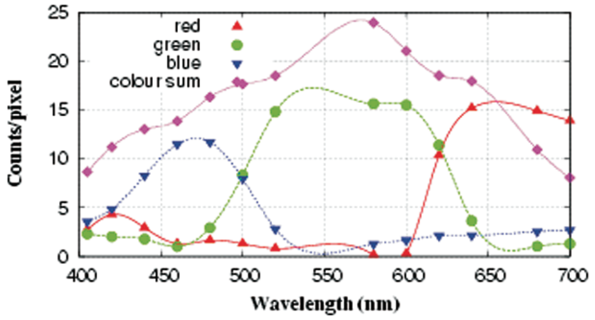

Figure 4. Results of test 3 on a Pentax K10D camera.

Figure 2 shows the total counts per pixel (for the three colour channel and the average) in a first test carried out by decreasing the exposure time whilst imaging a stable source. A second test was carried out by illuminating the camera with an LED and changing the LED pulse duration (keeping the exposure time fixed). The result is shown in figure 3 for an exposure time of 5s. Finally, figure 4 shows the results of a spectral response test, carried out by using a white light source and a monochromator.

Further tests are ongoing in order to characterize the two cameras.

A first application in an experiment of electron acceleration

Three Pentax cameras have been employed in an experiment (carried out at the ILIL laboratory) of electron acceleration driven by a 2TW femtosecond TiSa laser pulse focused with an f/5 optic onto a N gas-jet. In the experiment, a set of three SLR cameras including one K10D and two K100super was used.

One K100super camera was set used to image Thomson scattering at 90° from the laser propagation axis in the vertical plane. A second K100 super camera was set to

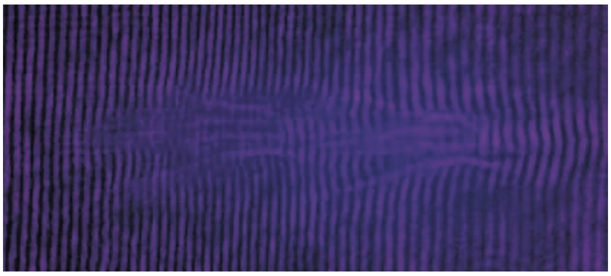

Figure 5. An example of an interferometric image of a plasma acquired by a K10D camera. The laser beam comes from the right (2 images are present due to the Nomarski scheme used).

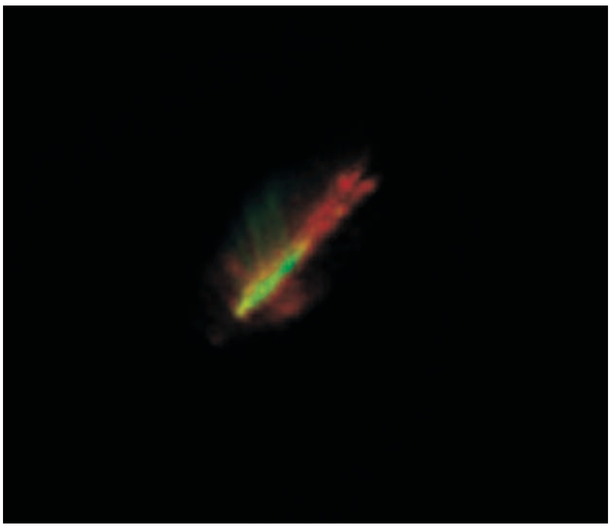

Figure 6. An example of a 90° Thomson scattering image acquired by a K100super camera. The laser beam comes from the upper right.

record the image generated by accelerated electrons on a LANEX screen, whose optical emission occurs at approximately 530 nm. The higher resolution K10D camera was set on the image plane of an optical interferometer to detect probe laser radiation at 400 nm.

As an example, figure 5 shows, in detail, an interferometric image of the plasma. In the colour image, the fringe shift pattern due to the contribution of the plasma refractive index is clearly visible and largely oversampled, making the overall resolution limited only by optical resolution that, in this case, was better than 10µm. Superimposed on the fringe pattern, a larger blue halo, due to the plasma self-emission is also visible. It is worth noting here that, in contrast to standard monochromatic low-cost CCD detectors for scientific applications, the usage of a three colour camera allows a more straightforward analysis in this case, with a noise removal mode given by the colour separation.

An example of an image from the Thomson scattering diagnostics is shown in figure 6. The Thomson image is taken, as already noted, at 90° from the main beam propagation direction. The image clearly shows optical emission from the plasma at different wavelengths.

Summary and conclusions

The use of digital SLR CCD cameras for optical diagnosis of laser produced plasmas has been tested. Two different models by Pentax have been considered. An ad hoc triggering board has been assembled and some preliminary tests on the camera have been carried out in order to estimate the dynamic range and the camera response as a function of wavelength. Results from an ongoing experiment demonstrate that such low-cost, large area cameras can be reliably and profitably used in some cases in place of more expensive and less feasible CCD or CMOS cameras.