Real-time Phase-Contrast Imaging

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Real-time x-ray imaging experiments, with typical evolution times in the 0.1 second range, are now possible at several ESRF beamlines. The FRELON (Fast REad-Out LOw-Noise) CCD camera, with 14-bit dynamic range and 1024 x 1024 pixel area, developed at the ESRF [1] is used on many of these beamlines. The standard solution to read this type of CCD camera data is using a SDV card directly plugged in the Sun workstation, and unified SPEC software. But this solution has not been able until now to take advantage of the full read-out speed of the FRELON camera (20 MPixels/s).

We present, in this short report, real-time phase images recorded on the ID19 ('Topography') beamline, using a VME system based on the VCCD3 card which allows one to record about 20 images / second on the complete area and with the full dynamic range. This system was developed in the Computing Services [2].

The VCCD3 Card

The VCCD3 VME card has on-board memory for image rebuilding, organized in two banks. While one bank is written/filled with the incoming pixels from the FRELON camera (new image), the other bank (previous image) is read/flushed into the VME memory card. The VCCD3 card allows:

- reading out the FRELON camera data over all 4 optical fibers to achieve the shortest possible read-out time (20 images/seconde).
- displaying a live image on a video display for monitoring purposes.
- summing up the data from the consecutive images of shorter duration when required.
- acquiring data in a continuous mode using the VME memory as a ring buffer; a pre-defined number of images can be stored after an interesting event (trigger).

The VCCD3 card stores the acquired images in a memory card, while BIT3 adaptor cards and fast link (25 MBytes/s) allow the online display program to be run on the Sun workstation and the data to be transferred in an efficient way. On the software side, the dedicated OS-9 device driver and server, as well as a special SPEC application, were used to both control the acquisition and to transfer the data.

First Results

The FRELON camera was equipped with an optics leading to a pixel size of 10 μm, a compromise allowing us to have reasonably short exposure times while retaining a fair spatial resolution. An energy of 20 keV was selected by the double-crystal (Si 111 in Bragg symmetrical geometry) vertical monochromator. For the first tests with a pure absorption object (stainless steel tip), the sample was located just before the x-ray converter (a Gd_2O_2S:Tb scintillator screen). For the final series of images of phase objects (gas bubbles in beer), they were placed at around 2.5 m from the camera in order to obtain the phase image through propagation (see papers by Buffiere *et al.*, and Baruchel *et al.*, in this Newsletter, pages 18 and 20). At this distance, we were in an edge detection regime, where black/white contrast appears at the border of the gas bubbles.

The images were corrected by subtracting the 'dark current' (without beam), and the 'flat field' images (with beam but without sample). A «fast» shutter (7 mm x 7 mm) was used to cut off the x-ray beam during the read-out time.

We tried to recreate the conditions of a real experiment in which we would have phase objects (thus, invisible in absorption) which move in some unpredictable way and whose behavior we wanted to track at a given moment. We found all these characteristics in the gas bubbles which appear inside a glass of beer (of course Champagne would also have been great, but it is more expensive). We took a series of data on several samples, using an exposure time of 50 ms which, together with the read-out time, yields a lapse of time of 100 ms between two consecutive images.

Figure 1 shows, as an example, a series of images recorded over a bubble source inside the beer. The emerging bubble is recognized when it has a diameter of ~ 30 μm. We can perfectly track its movement as it grows up to ø ~ 150 μm and its speed increases.

Conclusions

By using the FRELON camera at its full read-out speed, as carried out with the VCCD3 card, we could for the first time perform real-time phase-contrast imaging. The real-time display proved to be crucial for the success of the experiment.

The implementation of a fast read-out system well integrated within the standard ESRF hardware and software appears to be essential for the real-time image acquisition, which is of increasing interest for many users.

References

[1] J.C. Labiche, J. Segura-Puchades, D. van Brussel and J.P. Moy, FRELON camera: Fast Readout Low Noise, ESRF Newsletter N° 25, p 41-43, March 1996.

[2] C. Hervé, J. Cerrai, VCCD3 specification, version 0.4, CS/EL/95/0x.

Fig. 1: Phase-contrast images showing the formation and evolution of gas bubbles inside a glass of «white» beer (a Belgian beer which is opaque).