3rd International Conference on Tomography of Materials and Structures
Lund, Sweden, 26-30 June 2017, ICTMS2017-162

GigaFRoST – A HIGH-SPEED CAMERA READOUT SYSTEM FOR ULTRAFAST TOMOGRAPHY AT SUSTAINED kHz FRAME RATES

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Keywords: instrumentation, ultrafast x-ray tomography, high-speed image acquisition, dynamic studies, streaming image data

Summary: GigaFRoST is a high-speed camera and readout system custom-built at PSI designed to sustain kHz frame rate image acquisition over prolonged periods of time. It provides near real-time access to the image data stream during measurements, enabling live monitoring of dynamic changes in samples under *in situ* or *in operando* conditions. We will describe the system in detail and present examples of new experiments made possible only by its unique features.

1. INTRODUCTION

Developing the means to observe at a microscopic scale the full volumetric structural evolution of a sample during a dynamic process with both high temporal and spatial resolution has been a key challenge for the tomographic microscopy beamline TOMCAT [1] at the Swiss Light Source. Recently, we have achieved the acquisition of tomographical scans with 3 micrometers voxel size at 20 Hz [2], and were able to extend the time-resolution into the kHz regime for quasi-periodic motions [3].
One of the limiting factors in the investigation of complex dynamic processes has been the inability to (a) observe the process in real time, and (b) the relatively short total acquisition times available at high-frame rates. Both of these issues arise due to the fact that most commercially available CMOS detectors able to collect images at multi-kHz rates are designed for burst operation, storing the images in on-board memory. Data transfer from the camera is deferred until after the measurement and generally quite slow, hence no live preview of the data is possible. The available amount of internal memory limits the total number of frames that can be recorded, and is in many cases much too small to capture the entire duration of dynamic processes at a sufficient temporal resolution and field of view, precluding a sustained data acquisition.
The GigaFRoST development at PSI addresses these challenges by providing a custom-built readout system for a high-speed imaging chip.

2. THE GigaFRoST SYSTEM

GigaFRoST stands for "Gigabit Fast Read-out System for Tomography". The data collected by a pco.Dimax fast imaging sensor are read out by custom-designed readout electronics. Two data transfer boards directly stream data to the processing servers via eight parallel 10 Gbit fiber-optic links, reaching a transfer combined rate of 7.7 GB/s, which is sufficient to handle the maximum data rate produced by the chip (see Figure 1). In addition, a control board coordinates and manages the whole image acquisition process and runs an EPICS IOC to interact easily with the beamline controls system. On the server side, the partial image streams are reassembled into full frames in a large memory ring-buffer designed for high-frequency access. Independent processes can then access the data simultaneously to produce real-time previews or write data to permanent disk storage. Additionally, we plan to

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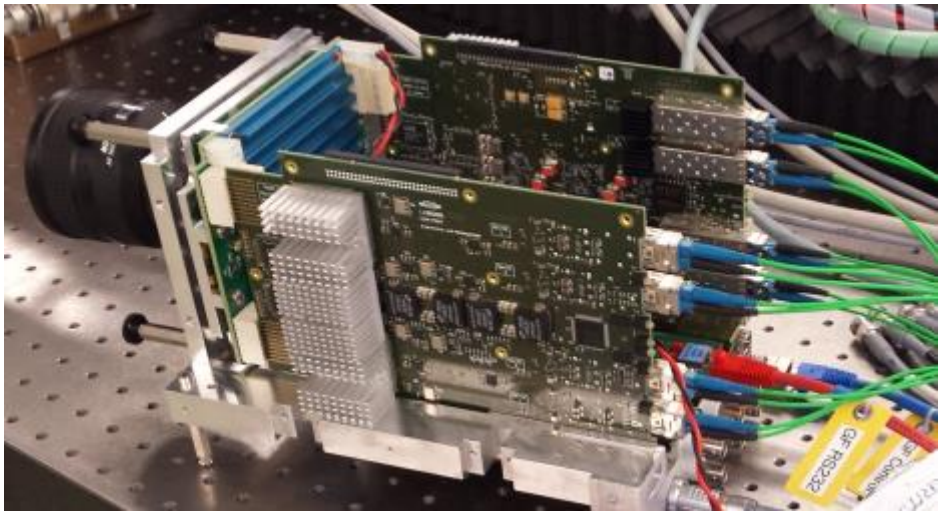
perform on-the-fly data reconstruction and analysis from the data stream to select only the useful data for storage or to provide on-line feedback to the experiment.
The GigaFRoST hardware also offers very flexible trigger and timing modes, providing an adaptable and versatile interface for complex *in situ, in operando,* and *in vivo* experiments.

3. SUMMARY AND FIRST RESULTS

GigaFRoST is in successful and reliable user operation at TOMCAT since about September 2015. In this talk, we will present an overview of the system architecture and its implementation at TOMCAT, as well as examples of experiments that will greatly profit from the GigaFRoST capabilities, ranging from the observation of crack propagation in metals [2], dendrite formation in cooling alloy melts, bubble growth in foams, and liquid transport in porous media [4], to *in vivo* measurements of lung tissue during breathing in mice [5] and the musculoskeletal motion of a fly thorax in flight [3]. The sustained high-speed acquisition has already enabled the detailed observation of sintering dynamics in volcanic materials in real-time for up to 30 minutes.



(a)

Figure 1: Custom readout electronics of the GigaFRoST camera. Visible are the two data transfer boards (dark green) connected to the pco.Dimax imaging chip (behind blue cooler), and the eight pairs of single-mode fiber-optic connections (light green) necessary to stream the data directly to the backend server.

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