# STATUS OF THE ULTRA FAST TOMOGRAPHY EXPERIMENTS CONTROL AT ANKA

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*Abstract*

X-ray imaging permits to spatially resolve the 2D and 3D structure in materials and organisms, which is crucial for the understanding of their properties. Additional temporal resolution of structure evolution gives access to dynamics of processes and allows to understand functionality of devices and organisms with the goal to optimize technological processes. Such time-resolved dynamic analysis of micro-sized structures is now possible by aid of ultrafast tomography, as being developed at the TopoTomo beamline of the synchrotron light source ANKA.

At TopoTomo, the whole experimental workflow has been significantly improved in order to decrease the total duration of a tomography experiment down to the range of minutes. To meet these requirements, detectors and the computing infrastructure have been optimized, comprising a Tango-based control system for ultra fast tomography with a data throughput of several 100 MB/s. Multi-GPU based computing allows for high speed data processing by using a special reconstruction scheme. Furthermore the data management infrastructure will allow for a life cycle management of data sets accumulating several TByte/day.

The final concept will also be part of the IMAGE beamline, which is going to be installed in 2013.

## INTRODUCTION

Third-generation light sources offer new possibilities for X-Ray imaging experiments. Fast imaging techniques became available, thanks to the high flux and to new fast CMOS detectors. One of the fields benefiting from is micro-tomography, where the speed-up is generating large data sets in a few seconds.

The reconstruction of these large 3D data sets was usually performed offline. Due to the reduced reconstruction time from initially several hours down to only a couple of seconds the reconstruction became part of the online data processing chain. For the TopoTomo beamline at ANKA [1, 2] a GPU-based ultrafast tomography framework (UFO) has been developed in order to merge all components of a tomographic scan into a homogenous workflow.

Remaining challenges concern the need for a high performant, but still reliable control system, embedded experimental workflow, a quick online rendering and visualization. The final evaluation is still done by commercial software. Last, but not least, for handling experimental data of up to several TByte/day, a data-and-life-cycle management has to be introduced.

## CONTROL SYSTEM OF TOMOGRAPHY

At ANKA the different layers (hardware, control, user interface) of a beamline communicate via the Tango software bus [3] (see Fig. 1). All hardware components are realized as Tango servers. Also the SCADA System WinCC-OA (PVSS2) [4] for vacuum control, etc., can been regarded as a Tango server. The Tango client SPEC [5] and its easy-to-handle macro language is used as command-line scripting interface to adapt the beamline optics and auxiliary elements to the specific experimental needs.

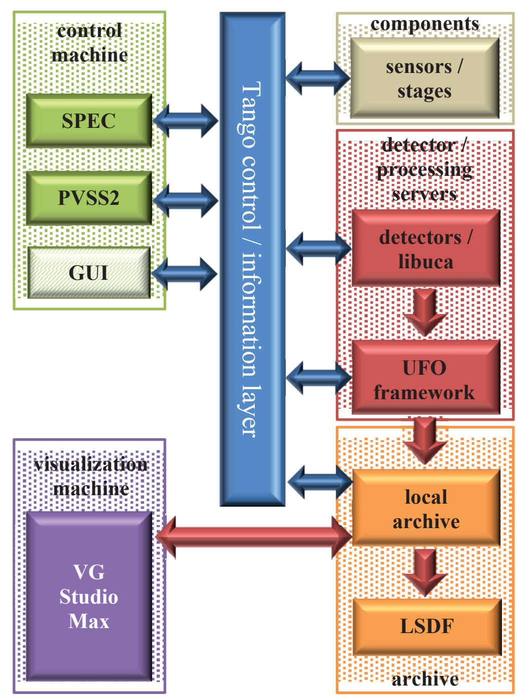


Figure 1: Communication (blue arrows) and dataflow (red arrows) between the different software layers and devices.

Instead of the slow overall-beamline control system, an optimization to reduce the total duration of a tomography experiment requires a significant improvement of the performance of all layers and of the IT infrastructure. For the software layer, the dead time (~ms) of a pure Tango-based software communication has to be replaced by hardware based triggering and the streaming of the data has to be designed carefully.

For the infrastructure of the TopoTomo beamline four servers (see Table 1) are involved in the workflow of a tomography scan. The different servers are connected to

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each other by a 10 Gbit fiber optics network, which reaches a data throughput of 700 MByte/s.

Currently, SPEC, running on the control machine, represents the front end to the user and manages the experimental workflow. Depending on the driver implementation, the Tango device servers for the detector are handled via a windows server or are connected directly to the Linux processing machine for better performance. Both paths are transparent to the UFO-framework via the libuca-library [6].

Table 1: Servers at TopoTomo

| Server | CPU | GPU | RAM | Hard disk |
|---|---|---|---|---|
| Control machine (user interface) | Xeon E5520 | Nvidia Quadro NVS 450 | 6 GB | 500 GB |
| Detector server (windows) | Xeon X5650 | none | 72 GB | 20 TB |
| Detector/Processing server (linux) | 2xXeon E5620 | 2xGeforce GTX 580 | 144 GB | 20 TB |
| Visualisation machine | 4xXeon W5590 | Nvidia Quadro FX 5800 | 148 GB | 3,7 Tb |
| | | Nvidia Tesla C1060 | | |

The high-speed tomography scan is initiated by SPEC via a software trigger to the detector, starting a continuous frame acquisition. Each frame of the detector generates a hardware trigger to the free-running rotation stage (*Aerotech*), which is precisely recording the angular position for every pulse. By avoiding a frame trigger for the command level, the total duration time of the scan is significantly decreased.

After the image acquisition during the scan, the image data of the detector, having a size of easily up to 160 GByte, together with the position data of the rotation stage are buffered on a local Raid 6 storage (16 drives). The further processing is done by the UFO framework (Ultra-fast X-ray Computer Tomography), which is described in detail in the next section. The data set can be reloaded and preprocessed via the framework. The volume reconstruction is done in minutes by a GPU based back-projection algorithm on the reconstruction machine.

The visualization of the reconstructed volume is done by VG Studio Max [7] on a dedicated visualization machine. Finally the data is archived at the Large Scale Data Facility [8], a storage supported by KIT.

## UFO-FRAMEWORK IN DETAIL

The highly optimized image processing algorithms are managed in a novel parallel computing framework. The framework ensures an optimal performance of the image-processing pipelines, while it provides a modular and extensible platform for shared development of these algorithms. The framework is intended for continuous processing of streamed data and covers the full signal chain with interface to the detectors, pre-processing, reconstruction algorithms and fast storage of the data.

The framework is implemented in C and uses the GLib standard library for basic data structures and algorithms. The core components follow the GObject object model to provide language bindings for arbitrary languages (such as Python or Javascript) [9]. The OpenCL API is used to exploit the parallel processing capabilities of recent GPUs for data processing, using a variety of hardware [10]. Although OpenCL is portable, users can provide optimized kernels for their algorithms depending on which hardware the kernel is executed on. Based on this core, developers implement filter nodes that either provide, process or store data. The processing may be executed using the GPU's, CPU's or both types of computational resources simultaneously. Data transfer from and to different devices are handled transparently, therefore users do not have to care explicitly about memory management. The nodes are then connected in a graph structure to describe the actual flow of computation as a composition of smaller sub-operations. At run-time, each filter node is then mapped to a computation thread and executed.

The implemented modules include input/output nodes, several pre-processing routines and the reconstruction code. Access to a variety of cameras is provided via the Unified Camera Abstraction library (libuca). It allows developers to use different cameras with a single software interface. Furthermore, a Python extension module is provided to allow developers to use Numpy/Scipy packages for processing the data.

## FIRST TOMOGRAPHY WORKFLOW TESTS

The efficiency of the different hardware and software layers within the fast tomography workflow was tested by a white-beam experiment at the TopoTomo beamline at ANKA.

### *Experimental Setup*

For the tomography scan a CMOS high speed detector (*Photron SA-1*) was used, which has a maximum frequency of 5400 frames/s at full-frame mode. The optics consists of a 74-µm-thick LSO:Tb scintillator and a ED eyepiece (*f*=180mm, numerical aperture (NA) 2.8 *Nikon Nikkor*) combined with an objective (*f*=50mm, max. NA 0.43, *Rodenstock TV- Heliflex*). Hence it results in a total magnification of 3.6x, which yields an effective pixel size of 5.5µm.

The image acquisition of the CMOS detector in combination with the rotation stage was synchronized during the tomography scan by hardware triggered pulses. The speed of the rotation stage was 450°/s by taking 2000 frames/s with the CMOS detector. Consequently, the total duration of the tomography scan with 800 projections takes 0.4s [11].



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*Results*

The tomography scan, described in the chapter before, was reconstructed once with PyHST [12] and secondly with the UFO framework. The overall reconstruction time of both algorithms is shown in Table 2.

Table 2: Duration of the Tomography Reconstruction

| **Algorithm** | **Overall reconstruction time** |
|---|---|
| PyHST | 31.3 s |
| UFO-Framework | 12.5 s |

The reconstructed volume (see Fig. 2) was rendered in VG Studio Max on the visualization machine.

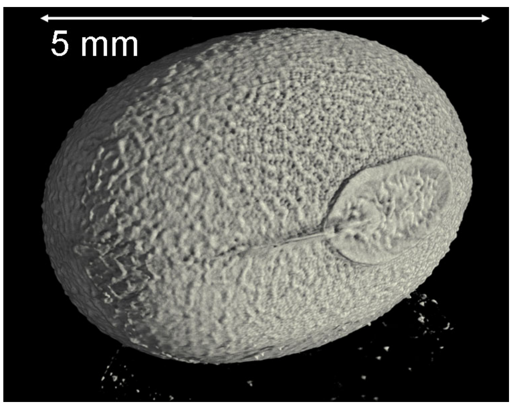


Figure 2: Volume rendering of an egg of the stick insect *Peruphasma schultei*.

## OUTLOOK

The current challenge is to organize and automatize the full experimental workflow, including the data management. Caused by the HDRI project [13], the main goals for the near future are to store the data, including metadata, in the Nexus [14] format and to implement a life-cycle management. The life cycle starts with the proposal of the user and ends with the archiving of the acquired data for a predefined period.

For a full automatization of the experiment partial manual operations, like sample exchange via a robot, succeeding rotation axes alignment, and autofocussing still needs to be fully automatized, so that the whole experiment can be operated by an inexperienced user via a graphical user interface.

All these tasks result in a considerable decrease of the overall time of a tomographic scan and make it more comfortable. The final concept will be implemented and further developed at the upcoming IMAGE beamline at ANKA.

## ACKNOWLEDGEMENTS

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