UFO Progress Report 2010

1 Scientific Progress

The first scientific results were achieved. A demonstrator high-speed tomography setup has been assembled at ANKA. It allows performing experiments up to several ten thousand frames per second. At the same time the setup serves as a platform for the intended online operation of the whole UFO data processing chain. The planned activities of this reporting period have been reached.

The existing detector and the new setup with streaming camera within the demonstrator beam line TOPOTOMO enable the execution of the important feasibility tests in summer 2011. The development of a fully programmable camera will allow us to evaluate the fast feedback loops in the detector system.

During a period of 4 weeks in November and December 2010 scientists of the Shubnikov Crystallography Institute (SCI) visited the KIT and worked closely together with KIT for the specification of the overall system design and the X-ray imaging setup.

The main administrative achievements in the reporting period are the organization of the collaboration and the specification of the various hardware and software components and systems. On 24th November 2010, one month after project approval by BMBF an official meeting with all project members (KIT, SCI Moscow, TPU Tomsk, UCA St. Petersburg) took place in Karlsruhe. This was the second face-to-face meeting of the UFO collaboration after the preparation meeting in spring 2010. To organize the collaboration between partners from Germany and Russia, the domain ***ufo.kit.edu*** has been registered. The server hosts the official web page [1] of the project and the UFO collaborative development platform including working group directories and code repositories. The collaboration platform is further used for bug tracking, monitoring of components progress and documentation. The minutes of the weekly project meetings at KIT and other project relevant documents are published on the server as well. Access to the central code repository is provided to all developers in order to ensure that the software developed is safely stored and available to collaborating partners from a single location. The Russian partners are provided with remote access to the GPU computing platform and are able to integrate and test their software components with most recent UFO hardware and software. An UFO mailing list has been created to synchronize the software development efforts.

The report is organized by the work packages given in the proposal.

1.1 WP1 Overall System Development and Monitoring

(Coordinator Dr. Thomas Weiss ISS)
The focus of this work package is the specifications and the overall system design of the UFO experimental stations initially planned to be built at ANKA. Subsequently a similar station will be developed at SIBIR-2 of the Kurtchatov Institute. The system specifications of the experimental stations have been determined based on the

experimental demands of potential scientific key applications (e.g. ultrafast radiography of reaction kinetics of catalytic processes or high-speed tomography of insect motion). These specifications were further refined and a conceptual design of the UFO stations has been established together with our Russian colleagues from the SCI during their visit in November/December 2010. This current conceptual design forms the basis for the UFO demonstrator experiments scheduled for June/July 2011 at the TOPOTOMO beam line at ANKA.

1.2 WP2 X-ray Imaging Setup

(Coordinators Prof. Victor Asadchikov SCI, Tomy dos Santos Rolo ISS)

Focus of this work package was the selection of components for the dedicated experimental station as well as its detector system. The final design will be based on the demonstrator high-speed tomography setup currently operating at the TOPOTOMO beam line.

1.2.1 Development of Sample Manipulators, Environment and Changer

The basic characteristics of the setup have been specified. This includes a fast and precise rotary axis based on an air bearing spindle with highest velocity of at least five thousand rounds per minute for high-speed tomography and a rotary ring rotation with up to 100 rounds per minute for laminography, where the beam is able to pass through the central aperture. These components will be placed on a motorized manipulator with two translational and two angular degrees of freedom. A lateral sample translation of 100 mm is foreseen, as well as a vertical sample translation of 50 mm. The angular degrees of freedom will be used to align the axis of rotation with respect to the detector pixels, and thus will have a small travel range of 5 degrees. The whole setup will be placed on an experimental table with adjustable height to accommodate the different beam offsets for white and monochromatic beam of 25 mm. The pitch and yaw angles of 2 degrees of the table will be used to align the detector while translating it along the beam.

The sample manipulators will be able to support high spatial (<1µm) resolution. An automatic sample changer system will be installed for the tomography and the smaller laminography samples (lateral extension <30mm), which allows for remotely selectable samples and a high sample throughput to guarantee an efficient use of available beam time once the station is in operation. However, larger laminography and radiography samples up to a lateral extension of about 200 mm can also be accommodated on the station using manual sample placement.

It has been decided that sample alignment for tomographic samples will be performed offline. On the one hand, the required signal and power cables of the alignment motors on the rotary axis cannot be connected via a slip ring or similar mechanism due to high rotational speeds. On the other hand, offline alignment increases the prospect to use the available beam time efficiently. Discussions with different manufacturers about the necessary customization have begun.

1.2.2 Development of Detector System

The broad range of possible applications for the UFO experimental station and therefore the necessary large range of acquisition parameters require the use of different cameras for the detector system. Three classes of cameras have been identified, namely an ultra high-speed camera for shortest integration times of 10 µs and highest image repetition rates of up to 100000 frames per second (fps), a high dynamic range camera with a contrast ratio of 20000:1 for high spatial resolution down to 1 µm and a fully programmable camera to implement the data driven fast reject and on-line control tasks of WP4. We decided to use the PCO.edge camera [2] to cover the high dynamic range and high-resolution tasks, and the CMOSIS CMV 2000 sensor [3] as building block for the fully programmable camera. Both cameras can stream the images with full speed to the data analysis subsystem. The evaluation about available ultra high-speed camera is ongoing.

Two configurations of the optical system are foreseen. The high-resolution configuration will provide diffraction limited optical resolution, to enable the acquisition of low-noise images with increased frame integration time. The high-speed configuration will be based on large aperture lenses, which exhibit some optical aberrations; however, shortest integration times with moderate spatial resolutions will be achievable. To use the available beam time as efficiently as possible and to support reproducible experimental parameter adjustments, a fully motorized detector system with automatic switching between the two optical configurations is foreseen.

1.3 WP3 Data Processing, Evaluation and Visualization

(Coordinators Dr. Suren Chilingaryian IPE, Dr. Anton Myagotin UCA)

The work in all three subtasks of work package 3 has begun. The first half year was dominated by activities common to all sub tasks: Coding standards, foundation of the frame work and development of the computing platform.

Highest priority had the discussion on the coding standards and the foundation of the UFO software framework. It should be flexible enough to be extendable for all later project phases and still allow rapid prototyping for new hardware or experimental setups. The second topic was the selection of a suitable computing platform. Latest technologies have been evaluated. Major components are a fast streaming camera, high-performance computing nodes, and fast storage solutions. The fast progress in the computing architectures will require continuous updates of the hardware. The flexibility of the computing framework is therefore crucial for the optimization of the computing hardware during the project.

1.3.1 Interfaces and Coding Standards

The partners have reached agreement on the software platform. The main components of the system will be developed in the programming languages C and C++. However, only pure C-style interfaces will be used for component integration. The standard template library is provided with Glib [4]. The GPU optimizations will be implemented using OpenCL [5]. To reach highest performance, the CPU code can be implemented using OpenCL, C, or inline assembly. The framework scripting will be done using Python. The GUI applications should be based on GTK/Glade [6]. The coding style and naming conventions have been fixed and published on the collaboration platform. The specification of basic interfaces is being finalized at the moment.

1.3.2 Software Framework for Parallel Computation

The first layer of the software framework will consist of the **U**nified **C**amera **A**ccess **Lib**rary (libUCA), UFO settings library, and a basic resource manager. The unified access to a number of cameras is crucial for the UFO project. The contributions of the three tasks in WP3 to the UFO software framework are listed below.

- The library libUCA provides unified access to the various cameras and frame grabbers used at the UFO setup. The API allows one to get and set camera parameters as well as to grab frames in synchronous and asynchronous modes (task 3.1).
- High quality noise reduction filters developed by TPU (task 3.2).
- PyHST. The initial version of optimized tomographic reconstruction code for CPU and GPU is available (task 3.2).
- UCA contributed a prototype implementation for laminography for CPU (task 3.2).
- A prototype GUI to control camera parameters has been developed (task 3.3).
- TomoViewer. A GUI to perform tomographic reconstruction is available (task 3.3).

1.3.3 Computing Platform

The computing platform is required for controlling the camera, acquiring image sequences, online pre- and post processing of image data, reconstruction and storage of the images. We have compared the performance of different GPU platforms in [7]. The proposed GPU server described there has been extended by a camera interface and local data storage. In the beginning of the project cameras with CameraLink interface like the PCO.edge camera [2] will be used. For the camera interface a dedicated PCIe-slot is foreseen. The server is equipped with fast local data storage for temporal buffering with write capability up to 1.3 GB/s. It is intended to store all data at the Large Scale Data Facility (LSDF) currently under commissioning at KIT [8]. The first version of the computing platform has been assembled at IPE and is now ready for commissioning at the TOPOTOMO beam line at ANKA.

1.4 WP4 Development of Online Process Control

(Coordinator Matthias Balzer IPE)
Due to the large number of pixels (i.e. 2 MPixel), fast reject algorithms are necessary to reduce the effective bandwidth. In order to increase the frame rate and preserve the same field of view of the target, the readout data format and a first fast reject algorithm has been defined. The development of the necessary FPGA infrastructure for a data driven fast reject and control tasks has started.

1.4.1 Selection of Sample Experiment

As a sample experiment to evaluate the functionality of the fast reject algorithm we chose a sequence of high-speed X-ray radiographs of merging bubbles in gelatinous agar. This sample is particularly challenging because of the presence of significant noise in the sample images, low contrast and the presence of fast changes in the images, with the occurrence in the range of frames per second.

1.4.2 Development of Fast Reject Algorithm

A first fast reject algorithm is developed using the interleaving feature of the selected camera. Each row of two consecutive frames is checked for differences. If a significant difference is detected, the trigger information about the position is generated. The data readout logic uses this trigger information to select the region of the data pixels to be sent to subsequent processing stages. The functionality of the fast reject algorithm has been successfully verified in software using the real image data from the sample experiment. Additional strategies and verifications for fast comparison will be investigated. The first fast reject algorithm will be implemented in the FPGA (hardware) as the next step.

1.4.3 Fully Programmable Camera

Available commercial cameras do not have enough flexibility for testing and/or verification of the reject algorithm online or feedback loops. Thus we chose to build a fully programmable camera based on the CMOSIS CMV2000 pixel sensor, which has fully configurable sensor properties (different modes of exposure time, high dynamic range, configurable analog and digital pixel features). The high data rate coming from the detector will be transferred to the Data Acquisition System using PCIe (Peripheral Component Interconnect express). The fastest commercial interfaces currently available support up to 700 MB per second in streaming mode. A DMA (Direct Memory Access) engine will be implemented in the FPGA in conjunction with the PCIe link to reach higher readout data rates.

2 Changes in Project Plan

There are no relevant changes in the project plan.

3 Left over money

The availability of the budget money for the institutes at Campus South has been extended until the end of February 2011 instead of the 31st December 2010. All orders were completed by the end of December 2011.
The total purchase commitment was 47.795,32 € at the 28th February 2011. After the completion of all orders two weeks later, 800 € remained.

The institutes of Campus North were not able to spend the total amount of funding in this reporting period due to late acceptance of the proposal. The reasons were the administrative delay to recruit suitable scientists and time intensive negotiations with potential distributors.

4 Prospects of Achieving Project Goals

There are no relevant changes in the project goals.

5 Collaborations with Third Parties

The optimization of the tomographic reconstruction code for GPUs is achieved in a close collaboration with the European Radiation Synchrotron Facility (ESRF) in Grenoble and the KIT. The legal basis for this collaboration is the contract between ESRF and KIT with the contract number N CL 0122.

KIT takes part in the national “High Data Rate Processing and Analysis Initiative” (HDRI) founded by the six national research centers in the German Helmholtz programme Research with Photon, Neutron and Ions (PNI).

6 Results from Third Parties

An image processing pipeline for tomographic reconstruction has been published in [9].

An increasing number of groups are developing optimized algorithms for GPUs for a wide area of applications. To the best of our knowledge there no other reconstruction implementation faster than our code is currently available.

7 Results Achieved to Date and Impact

7.1 List of Publications

In the reporting period several peer-reviewed papers were accepted for publication and several contributions to conferences and workshops were made.

S. Chilingaryan, A. Mirone, A. Hammersley, C. Ferrero, L. Helfen, A. Kopmann, T. dos Santos Rolo, P. Vagovic: *A GPU-based Architecture for Real-Time Data Assessment at Synchrotron Experiments.* Accepted for publication by IEEE Trans. Nuclear Science.

S. Chilingaryan, A. Mirone, A. Hammersley, C. Ferrero, L. Helfen, A. Kopmann, T. dos Santos Rolo: *A GPU-based Architecture for Real-Time Data Assessment at Synchrotron Experiments.* GPU Technology Conference, San Jose USA, Sept. 20-23, 2010.

S. Chilingaryan, A. Mirone, A. Hammersley, C. Ferrero, L. Helfen, A. Kopmann, T. dos Santos Rolo: *A GPU-based Architecture for Real-Time Data Assessment at Synchrotron Experiments.* PNI-In House research NANO & MICRO Sciences and Technologies Workshop Karlsruhe, Dec. 2–3, 2010.

T. dos Santos Rolo, T. van de Kamp, A. Ershov, E. Reznichenko, V. Reznichenko and T. Baumbach: *High-speed micro-tomography at ANKA: applications and visualisation.* ANKA User Meeting, Karlsruhe, Oct. 7-8, 2010.

T. van de Kamp, T. dos Santos Rolo, P. Vagovic, A. Cecilia, A. Riedel and T. Baumbach: *Insect Imaging at ANKA - Visualization and Applications*. Karlsruhe, Oct. 7-8, 2010.

T. dos Santos Rolo, B. Zienicke, V. Altapova, A. Cecilia, A. Ershov, T. van de Kamp, P. Vagovic, D. Pelliccia, T. Lamparter, and T. Baumbach: *High speed micro-tomography at ANKA: implementation and first applications.* XTOP Conference ,Warwick (UK), Sept. 20-23 2010.

T. van de Kamp, T. dos Santos Rolo, A. Riedel, H. Greven and T. Baumbach: *Insect tomography at ANKA: applications and visualization.* XTOP Conference, Warwick (UK), Sept. 20-23 2010.

V. Altapova, J. Butzer, T. d.S.Rolo, P. Vagovic, A. Cecilia, J. Moosmann, J. Kenntner, J. Mohr, D. Pellicia, V.F. Pichugin and T. Baumbach: *X-ray phase-contrast radiography using a filtered white beam with a grating interferometer*, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. Doi:10.1016/j.nima.2010.12.218, 2011.

В. Альтапова, А. Ершов, Т.д.С. Роло, Е. Резникова, Ю. Мор, Ю.Л. Пивоваров, В.Ф. Пичугин, и Т. Баумбах. "МЕТОДЫ ВИЗУАЛИЗАЦИИ И ИХ ПРИМЕНЕНИЕ НА ИСТОЧНИКЕ СИ ANKA KIT", Поверхность: Рентгеновские, синхротронные и нейтронные исследования.В печати.
(V. Altapova, A. Ershov, T.d.S. Rolo, E. Reznikova, J. Mohr, Yu.L. Pivovarov, V.F. Pichugin, and T. Baumbach: *Imaging Methods and their Application at ANKA Light Source*, Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques. In press.)

7.2 Patents

No patents were issued within the reporting period.

7.3 Long-term Prospects

The intended online processing and reconstruction will enable interactive experiments at beam lines replacing the current time-consuming offline processing of results.
The development of feedback control loops will empower the usage of instable set points and so enable new applications in X-ray physics.

8 Student Work

Three PhD students are currently working on the UFO project. No student projects have been completed in the reporting period.

9 References

[1] UFO project homepage. http://www.ufo.kit.edu
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[3] CMOS image sensor CMOSIS CMV2000. http://www.cmosis.com/products/standard_products/cmv2000
[4] GNOME library, http://developer.gnome.org/glib/
[5] OpenCL - The open standard for parallel programming of heterogeneous systems. http://www.khronos.org/opencl/
[6] Glade - A User Interface Designer. http://glade.gnome.org/
[7] Suren Chilingaryan, Alessandro Mirone, Andrew Hammersley, Claudio Ferrero, Lukas Helfen, Andreas Kopmann, Tomy dos Santos Rolo, Patrik Vagovic *A GPU-based Architecture for Real-Time Data Assessment at Synchrotron Experiments*. Accepted for publication by IEEE Trans. Nuclear Science.
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[9] C. Hintermüller, F. Marone, A. Isenegger and M. Stampanoni: *Image processing pipeline for synchrotron-radiation-based tomographic microscopy.* J. Synchrotron Rad. (2010). **17**, 550-559.