UFO – Project

WP1: Performance Requirements

This documents defines the minimal system specifications and performance requirements that the planned experimental station for the UFO project aims to fulfill. These requirements are mostly based on selected scientific experiments, the so-called use cases listed below, which would either be impossible to perform without or would greatly benefit from the existence of the UFO experimental station. These use cases are to some extend similar to the scientific applications mentioned in WP5 but are more specific than those. They are chosen to highlight certain limiting performance aspects of the setup.

General

Imaging techniques:	fast radiography ≥ 100kHz frame rate fast tomography ≥ 100Hz tomogram rate laminography
Contrast methods:	absorption, phase (propagation based and grating), spectroscopic

Camera/Optical System

Spatial resolution:	≤ 1 um in 3-D, (at full tomographic speed)
camera position (x,y):	≤ 1 um
camera distance:	≤ 10 um
Field of View:	≥ 3 mm with full spatial resolution ≥ 12 mm (vertical beam size) at reduced resolution
Frame rate:	≥ 1000 fps at full pixel resolution; ≥ 100 000 fps at reduced resolution
other features:	automatic change/optimization of - scintillator thickness, camera focus, magnification, - camera position (perpendicular to the beam), - camera distance (position along the beam)

Sample stage tomography

rotation speed:	≥ 10000 rpm
total sphere of confusion:	≤ 1um
max. sample size:	≥ 30 mm (with changer), ≥ 200 mm (manual loading) *(typical sample sizes for tomography are up to several mm in lateral extension; but the sample changer should be capable of accommodating samples up to about 30 mm;* *using manual sample loading larger samples up to 200 mm (e.g. for radiography) should be allowed*
max. load	≥ 10 g *(≥ 100 g at reduced speed; tomography samples typically weigh less than a few grams)*

Sample stage laminography

rotation speed:	≥ 100 rpm
total sphere of confusion:	≤ 1um
max. sample size	≥ 200 mm
laminography angle:	- 45° … 45°
max. load:	≥ 0.5 kg *(at full speed operation)*

Sample Changer

max. sample size:	*tomography* ≥ 30 mm *laminography* ≥ 50 mm
speed:	≤ 10 sec/sample *(assuming less than one second for the data taking we get a throughput of about 6 samples / minute or 360 samples / hour if run continuously)*

Control System/Software

Motor Control

The control system of the station should have extensive capabilities to automatically adjust experimental parameters not only during experimental setup but also during the measurements (within the limits and preferences specified by the user) to optimize the quality of the collected data. The optimization will be driven by on-the-fly image analysis and feedback. As an example: it should be possible to compensate for movements of the image (or the region of interest inside an image) caused by change of sample properties or beam fluctuations.
Adjustable parameters will need to include:

- choice of scintillator, lens combination and camera
- energy range, filter setting, beam shutter, slit settings
- camera distance and xy-position
- sample position (automatic centering)

Data about the position of each motor in the setup and the relevant beam line components should be collected at least at the rate the image data is acquired and stored with the image.
The motors of the setup can be divided into the following motor groups:

- table
- tomography sample stage
- laminography sample stage
- camera
- sample changer
- beam line components

Within each of the above motor group (with exception oft the beam line components) all motors should be able to move simultaneously on predefined and optimized multidimensional trajectories.

Fast Reject/Smart Trigger

A fast reject/smart trigger mode for data acquisition will be available to start the image acquisition (i.e. streaming to the subsequent reconstruction pipeline and storage) depending on the content of the image and other data coming from the setup or beam line components (e.g. information about sample or beam position).

Reconstruction Pipeline

A highly parallel and efficient software pipeline will be set up to start the 3D reconstruction of the tomographic and laminographic data as soon as data is made available by the camera.

Scientific Use Cases

Use case 1:
tomography of cement-based materials during hardening – time evolution and sample statistics

High resolution micro-tomographic imaging to investigate the development and evolution of the 3D-microstructure (e.g. pore connectivity and tortuosity) of cement-based materials in relation to their composition and environmental parameters. The experiment requires a high spatial resolution (< 1um). A combination of tiling and helical tomography will be required for typical sample sizes.

Tomography (absorption contrast, potentially spectroscopic contrast)

critical parameters:
- high spatial resolution (≤ 1um) in 3D
- throughput (few sec per sample)
- large field of view (≥ 3mm)

secondary parameters:
- time per tomogram
- energy resolution

Use case 2:
morphological comparison of zebrafish – sample statistics

To examine phenotype and morphology in (juvenile) zebrafish using x-ray tomographic imaging; screening the natural diversity by using high-throughput methods sampling large amounts of specimen in a short time

Tomography (phase contrast)

critical parameters:
- high throughput (few seconds per sample)
- contrast

secondary parameters:
- high resolution(≤ 1um) in 3D

Use case 3:
in-vivo studies of insects kinematics – fast time dependence

detailed 3D in-vivo observation of the kinematics of insect motion (e.g. feeding and walking). Fast automatic optimization of image contrast by image based feedback, as the observation is in-vivo and the radiation dose should be minimized to maximize live time of the specimen.

fast Tomography

critical parameters:

- high frame rate (≥ 20 tomograms/s)
- optimal contrast/dose ratio

secondary parameters:

- high spatial resolution (≤ 1 um)
- large field of view

Use case 4:
reaction kinetics of catalytic processes – fast time dependence

Monitoring the onset and spatio-temporal evolution of the catalytic processes with ultra-fast radiography. The onset of the reaction hard to predict – fast reject of images with 'nothing happening' required. Spectroscopic contrast important.

ultra-fast Radiography - spectroscopic contrast

critical parameters:

- frame rate (≥ 100 kHz)
- large FOV (several cm)
- energy bandwidth ($\sim 10^{-4}$)

secondary parameters:

- spatial resolution (≤ 10 um)

Use case 5:
X-ray imaging of cultural heritage objects - Laminography

X-ray imaging with absorption and/or spectroscopic contrast of cultural heritage objects (art work, paintings, fossils) to identify elemental distribution and internal structure.

laminography – large objects

critical parameters:

- large samples / large FOV
- energy BW (for spectroscopic contrast)
- dose

secondary parameters:

- time per sample
- spatial resolution (≤ 10 um)

Use case 6:
microstructure devices: quality assurance/failure analysis - Laminography

monitoring microstructure of devices along the technological production line as a step to assess quality and investigate failure sources.

laminography – high throughput

critical parameters

- throughput
- large field of view
- spatial resolution

secondary parameters:

- dose
- contrast