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X-ray Grating Interferometry design for the 4D GRAPH-X system

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Corresponding author email: alessandra.patera@to.infn.it

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Purpose: The 4D GRAPH-X (Dynamic GRAting-based PHase contrast X-ray imaging) project aims at developing a prototype of an X-ray grating-based phase-contrast imaging scanner in a laboratory setting, based on the Moirè single-shot acquisition method. It is optimized for analysing moving objects, so that it could evolve into a suitable tool for biomedical applications (with main focus on lung imaging [1-4]). The system provides information about the spatial distribution of the linear attenuation coefficient, the phase-shift (i.e., the refractive index decrement) and the scattering properties of the sample (namely, the dark-field signal), generating three independent 3D images with a simultaneous acquisition [5]. Wave field simulations are performed in order to optimize the geometric parameters and construct a high resolution and sensitive imaging setup. In this work, the design and construction of a dynamic imaging setup using a conventional milli-focus X-ray source is presented.

Materials and Method: The 4D GRAPH-X system for X-ray phase-contrast imaging based on Talbot-Lau grating interferometry, installed in a radiation-protected area of the Physics Department at the University of Torino, Italy, is at the moment the only lab-setting for grating-based phase-contrast X-ray imaging in Italy. The system consists of a source, a detector and a set of three gratings: G0, G1 and G2 gratings. The X-ray source is an ordinary GE Eresco 160 MF4-R X-ray tube with a millimetric focal spot size and a tungsten anode. A 0.5 mm thick Titanium filter is inserted in front of the source in order to model the energy spectrum with a peak around the design energy (i.e., 45 keV). The detector is a flat panel with a CMOS active part with a 114 × 146 mm2 sensitive area and a 49.5 µm pixel pitch. The gratings were fabricated by bottom up electroplating of Au into Silicon structures etched by deep reactive ion etching [6]. Grating structure and inter-grating distances are defined by simulations. A schematic view of the setup is reported in Fig.1. As a specimen, a 3 cm thick and 5 cm long anthropomorphic dynamic thorax phantom, similar to the one described in [7], is under construction in collaboration with the University of Florence. The phantom simulates a male torso containing moving structures capable of reproducing realistic lung lesions movements. While the external phantom surface is 3D printed using as reference a real patient CT acquisition (and then rescaled to a small phantom size to be suitable with the 4D GRAPH-X system), internal parts are made with materials mimicking lungs, muscles and ribs density and attenuation. Water Equivalent Inserts (WEIs) simulating spherical tumors can be positioned into the lungs in different locations. An Arduino programmable board drives a step-motor to move the spheres along linear paths.

Results and discussion: Optimization by wave front simulations led to a symmetric configuration with 5.25 µm pitch at third Talbot distance and 45 keV design energy. The spectral visibility responses at 1.5 m source-to-detector distance at the three T.O. are shown in Fig. 2. The mean visibility is of the same order of magnitude in the first three T.O. (specifically, 1: 25%, 3: 22%; 5: 24%). The main sources of errors on the visibility values depend not only on the photon statistics but also on the number of phase steps, the actual phase shift and the interferometer type. In a lab-setting, it is recommended to acquire at least 7 steps to keep the error below 1% [8]. The optimized grating parameters are used in the Monte Carlo simulation in order to estimate the transmission percentage after each system element. Results show a transmission percentage of about 20% after passing through all the gratings and the phantom. The simulated system performance is being validated both using a table-top setup at PSI and at the University of Torino, as noise in phase contrast imaging is highly dependent on the visibility. The system parameters are tuned in order to investigate the potential of the setup for dynamic imaging in view of future applications in lung imaging.

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Figure 1: Schematic view of the 4D GRAPH-X system.

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Figure 2: Spectral visibility as a function of the energy for T.O. = 1, 3, 5. Gratings pitch: 5.25 μm at 45 keV energy.

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Primary author: PATERA, Alessandra (TO)

Co-authors: Dr ARBOLEDA, Carolina (Swiss Light Source, Paul Scherrer Institute (PSI), Villigen Switzerland.); Dr CALUSI, Silvia (University of Florence, Department of Experimental and Clinical Biomedical Sciences, Italy.); FERRERO, Veronica (TO); FIORINA, Elisa (Istituto Nazionale di Fisica Nucleare); Dr JEFIMOVS, Konstantins (Swiss Light Source, Paul Scherrer Institute (PSI), Villigen Switzerland.); Dr JOSELL, Daniel (Materials Science and Engineering Division, National Institute of Standards and Technology (NIST), Gaithersburg, Maryland 20899, USA.); Mr LISCI, Riccardo (University of Florence, Department of Agricolture, Food Enviroment and Forestry, Florence, Italy); LO GIUDICE, Alessandro (TO); MAS MILIAN, Felix (TO); MEREU, Paolo (TO); Dr MOFFAT, Thomas (Materials Science and Engineering Division, National Institute of Standards and Technology (NIST), Gaithersburg, Maryland 20899, USA.); PALLOTTA, Stefania (FI); Dr POLIKARPOV, Maxim (ETH Zurich, Department of Information Technology and Electrical Engineering, Zurich, Switzerland.); RAMELLO, Luciano (TO); RE, Alessandro (TO); Prof. STAMPANONI, Marco (Swiss Light Source, Paul Scherrer Institute (PSI), Villigen Switzerland.); Dr SHI, Zhitian (Swiss Light Source, Paul Scherrer Institute (PSI), Villigen Switzerland.); VISCA, Lorenzo (TO); CERELLO, Piergiorgio (TO)

Presenter: PATERA, Alessandra (TO)

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