Introduction to Code Aperture Imaging, Phase Imaging, and Differential Phase Contrast Imaging for DICOS v03

Abstract:

There have been recent advances in X-ray technology that will eventually make their way into the Digital X-rays (DX) and Computed Tomography (CT) of security equipment implementation and DICOS. The three most promising are Coded Aperture Imaging (CAI), Phase Contrast Imaging (PCI), and Differential Phase Contrast (DPC) imaging. CAI and PCI are exceptional cases of DPC and will be treated as a subset of DPC in DICOS. This document provides a short description of each of the three X-ray technologies and figures showing how they relate to grating locations for DPC.

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TWG: 1

Background

There have been advances in X-ray technology that will eventually make their way into the Digital X-rays (DX) and Computed Tomography (CT) of security equipment implementation and DICOS. The three most promising are Coded Aperture Imaging (CAI), Phase Contrast Imaging (PCI), and Differential Phase Contrast (DPC) imaging. CAI and PCI are exceptional cases of DPC and will be treated as a subset of DPC in DICOS. This document provides a short description of each of the three X-ray technologies and figures showing how they relate to grating locations for DPC.

Differential Phase Contrast Imaging

A novel X-ray imaging method, Talbot-Lau grating interferometry enabled X-ray phase-contrast imaging, can simultaneously capture three types of unique object information from one set of acquired data: Absorption, Differential Phase Contrast (DPC), and Dark-Field (DF). A high-level implementation is shown in Figure 1.

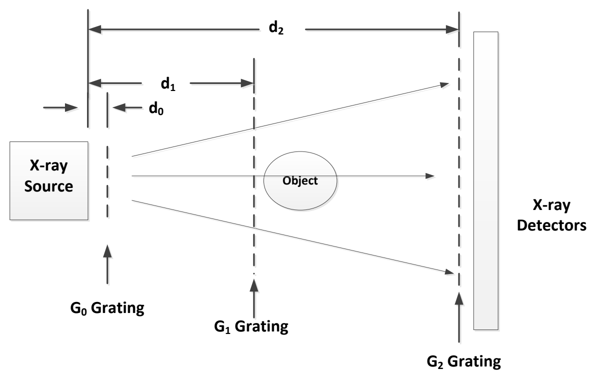


Figure 1. High-level schematic of a DPC Imaging System. This G_0 is the Coherent grating next to the X-ray source, G_1 is the Object or Phase Grating, and G_2 is the Analyzer Grating in front of the X-ray detectors. The distance from G_0 to the X-ray source is d_0, G_1 to the X-ray source is d_1, and the distance from G_2 to the X-ray source is d_2.

Studies have found that the DPC signal could provide superior contrast performance for certain low-density, low *Z* materials compared to the conventional absorption contrast. Besides, the DF signal is susceptible to specific delicate structures such as element composition. Due to these potential advantages, numerous research interests have been attracted with the hope of translating such novel X-ray imaging methods into security applications.

Despite these likely advancements, however, the low radiation dose efficiency of the Talbot-Lau interferometer strongly impedes its wide applications. This is mainly due to the photon absorption on the analyzer grating. The pitch or frequency of the gratings will be a function of the adequate energy of the X-ray beam. Usually, the analyzer grating blocks more than half of the photons that have already penetrated through the object. The three different images are generated from the same set of X-Ray detectors. There are various methods of reconstructing the three additional images from the captured X-ray detector data. The most popular implementation is based on the Fourier Transform, but other reconstruction methods can be found in present research publications.

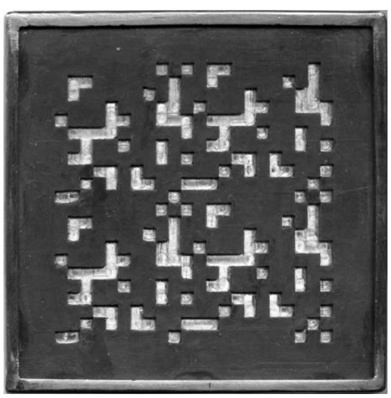
Coded Aperture Imaging

The energy of hard X-rays is too high to be reflected or refracted and cannot be focused by lenses or mirrors as for visible light. Image modulation by apertures is therefore often used instead.

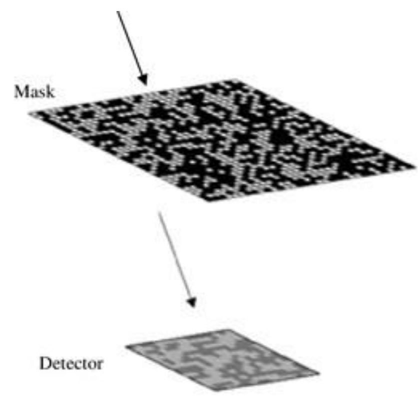
Coded apertures or coded-aperture masks are grids, gratings, or other patterns of materials opaque to various wavelengths of electromagnetic radiation. The wavelengths are usually high-energy radiation such as X-rays and gamma rays. A coded "shadow" is cast upon a plane by blocking radiation in a general pattern. The properties of the original radiation sources can then be mathematically reconstructed from this shadow.

In a coded aperture implementation, images from multiple apertures will overlap at the detector array. It is thus necessary to use a computational algorithm, which depends on the precise configuration of the aperture arrays, to reconstruct the original image. By using this algorithm, a sharp image can be achieved without a lens. Furthermore, the image is formed and tolerant to faults in individual sensors.

One arrangement using a mask is shown in Figure 2a. The wavelengths are usually high-energy radiation such as X-rays and gamma rays. By blocking radiation in a known design, common patterns are shown in Table 1; a coded "shadow," as shown in Figure 2b, is cast upon a plane. A high-level schematic of a layout of a CAI system is shown in Figure 3.



(a) Mask Layout



(b) Imaging on the X-ray detectors

Figure 2. (a) A typical mask placed right after the X-ray tube (b) the shadowing of the mask on the X-ray detector array.

Table 1, Listing of some standard CAI masks taken from [1]

Description Based on	Implementation
Identity Matrix	Coordinate or polar
Hadamard Matrix	Coordinate or polar
Random Binary Matrix	Coordinate or polar

Sinusoid in *x* (horizontal) and a quadratic residual in *y* (vertical)	Coordinate or polar

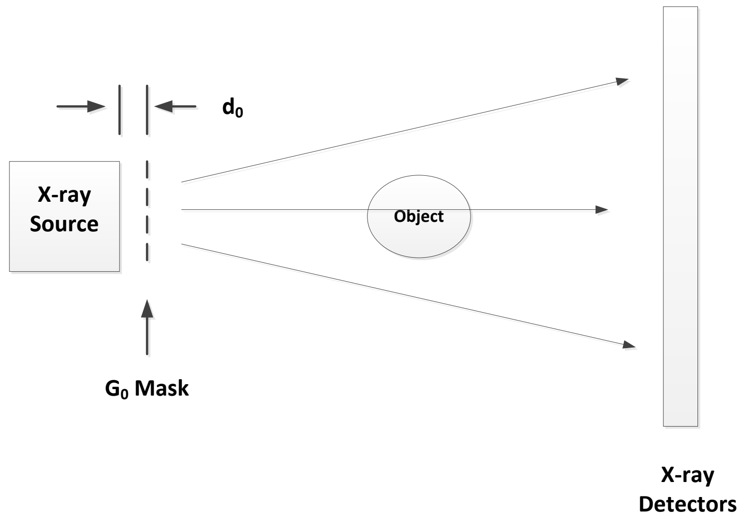


Figure 3. High-level schematic of a CAI system. G_0 is the mask or grating next to the X-ray source. The d_0 gives the distance from the mask to the X-ray source.

Phase Contrast Imaging

PCI, also known as phase-sensitive X-ray imaging, is a general term for different technical methods that use information about changes in the phase of an X-ray beam that passes through an object to create its images. Standard X-ray imaging techniques like DX or CT rely on decreasing the X-ray beam's attenuation when traversing the object of interest, which can be measured directly with X-ray detectors. In PCI, however, the beam's phase shift caused by the object of interest is not measured directly. Still, it is transformed into variations in intensity, which the detector can then register. A high-level diagram is shown in Figure 4.

In addition to producing projection images, PCI, like a conventional transmission, can be combined with tomographic techniques to obtain the 3D distribution of the fundamental part of the refractive index of the object of interest. When applied to samples of atoms with low atomic number *Z*, PCI is more sensitive to density variations in the example than conventional transmission-based X-ray imaging.

Various PCI techniques have been developed, all of which are based on observing interference patterns between diffracted and undiffracted waves. The most common procedures are crystal interferometry, propagation-based imaging, analyzer-based imaging, edge-illumination, and grating-based imaging.

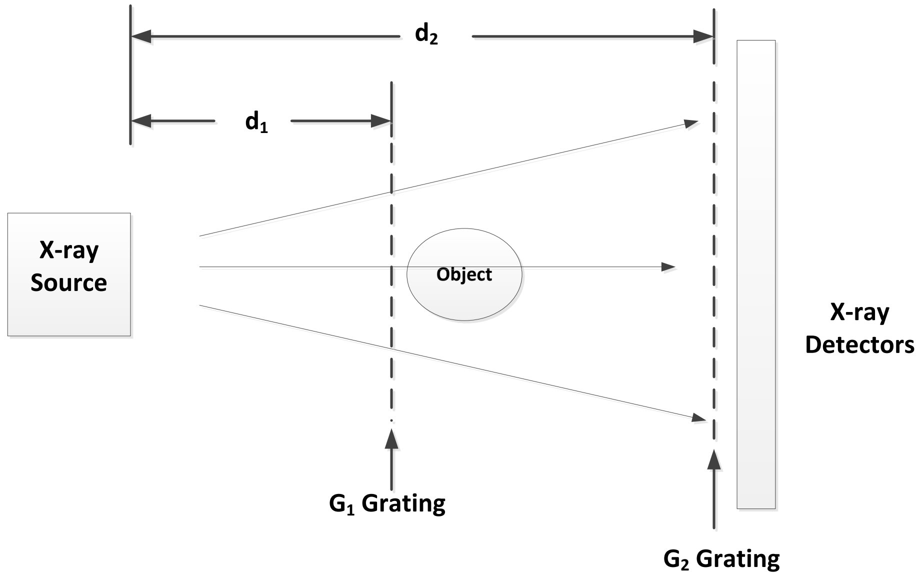


Figure 4. High-level schematic of a PCI System. In this case, the Object or Phase Grating is G_1, and the Analyzer Grating in front of the X-ray detectors is G_2. The distance from G_1 to the X-ray source is d_1, and the distance from G_2 to the X-ray source is d_2.

References

[1] Brady, David J.; Marks, Daniel L.; MacCabe, Kenneth P.; and O'Sullivan, Joseph A., ,"Coded apertures for x-ray scatter imaging." Applied Optics.52,32. 7745-7754. (2013).

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ACRONYM LIST

CAI	Coded Aperture Imaging
CT	Computed Tomography
DF	Dark Field
DICOS	Digital Imaging and Communications in Security
DPC	Differential Phase Contrast
DX	Digital X-rays
PCI	Phase Contrast Imaging