An improved acquisition scheme for the reverse projection method

C Wei¹, Z Wu²*, F Wali¹, R Luo¹, and Y Tian¹*

¹ National Synchrotron Radiation Laboratory, University of Science and Technology of China, Hefei, Anhui 230029, People’s Republic of China
*Correspondence e-mail: wuzhao@ustc.edu.cn ychtian@ustc.edu.cn

Abstract. In recent years, efforts have been made on the information extraction method in x-ray grating-based phase contrast imaging. Among them, the reverse projection method proposed by P.P.Zhu in 2010 features as a fast, low-dose method to extract information without stepping the gratings. It enables to extend the phase contrast imaging system to the vivo studies. However, it has strict requirement on the system stability and the source stability. In this manuscript, an improved acquisition scheme has been proposed using a staggered grating making the reverse projection method more efficient with a lower requirement of the system and source stability.

1. Introduction
Thanks to the high contrast to the soft tissues, x-ray phase contrast imaging method has been studied for many years [1-7]. It has been developed four main methods named crystal interferometer imaging [5], propagation-based imaging [6], diffraction-enhanced imaging [7] and grating-based imaging [1-4]. Among them, grating-based imaging method is the one which can be carried out on the conventional x-ray tubes along with synchrotron sources. So it is the most promising method and has potential to be implemented in clinical applications.

Meanwhile, many information extraction methods have also been developed [8-15] and the most influential method is called phase stepping procedure [2, 15]. This method can extract absorption, differential phase and scattering signals simultaneously and accurately by stepping the analyzer grating two or more steps in its one period evenly. The main limitations of the stepping procedure is the requirement of additional scanning of the gratings thus high mechanical stability and calibration, compared with the continuous scanning mode used in attenuation based x-ray computed tomography. Therefore, information extraction method without stepping gratings is necessary in order to translate x-ray grating interferometry from laboratories to hospitals [8-12].

In the last decade, researchers have proposed many information extraction methods. Among these methods, reverse projection method [8] is of great significance because it utilizes the conjugate characteristic of the mutual reverse projections to extract absorption and differential phase signals by once circular scanning. The advantages of the reverse projection method are fast and efficient. However, it imposes a very strict requirement on source and system stability because of asynchronous reverse projections. In another word, time interval between two collections is so long that most of the conventional x-ray tubes can’t reach the stability requirement. Meanwhile, a slight vibration or drift of the system in acquiring images, and the slight misalignment may cause inaccuracy.
In this manuscript, an improved acquisition scheme collecting the conjugate images directly in single shot using a staggered grating is proposed. This method thus reduces the strict restriction on the source and system stability.

2. Methods
To acquire the upslope image and downslope image in single shot, a staggered analyzer grating [12] with half period of the analyzer grating shift between each layer has been shown in figure 1. The height of the layer equaled to the size of the detector pixel. It is worth mentioning that if the upper layer can be precisely positioned at the upslope when collecting data, the down layer should be naturally positioned at the position of the downslope. Therefore, using this analyzer grating, the upslope image and downslope image can be acquired simultaneously and accurately in single shot. While the cost is that the spatial resolution in the direction parallel to the linear grating structures should decrease to half of that with the conventional analyzer grating. However in some fields, the effect caused by spatial resolution loss in the direction parallel to the linear grating structures can be compromised.

![Illustration of grating interferometer](image1)

Figure 1. Structure of the staggered grating

Using reverse projection method and our proposed staggered grating structures, the improved information extraction formula can be expressed as

\[
M(x_r, 2z-1, \phi) = M(x_r, 2z, \phi) = \ln \left( \frac{2I_0 S(x_g)}{I(x_r, 2z-1, \phi) + I(x_r, 2z, \phi)} \right) \tag{1}
\]

\[
\theta(x_r, 2z-1, \phi) = \theta(x_r, 2z, \phi) = \frac{1}{C} \frac{I(x_r, 2z-1, \phi) - I(x_r, 2z, \phi)}{I(x_r, 2z-1, \phi) + I(x_r, 2z, \phi)} \tag{2}
\]

Where z-axis is in the direction parallel to the linear grating structures, and x_r-\phi plane is shown in figure 2. M means the attenuation term of the sample while \theta is defined as the refraction angle caused by the sample. I_0 is the initial x-ray intensity from the x-ray tube and I is the x-ray intensity recorded by the detector. S(x_g/D) stands for the shifting curve, which can be expressed by a first-order Taylor expansion at its half slopes with

\[
C = \frac{1}{S(x_g/D)} \frac{dS(x_g/D)}{d\theta}.
\]

3. Simulations
In this work, Talbot Interferometer imaging system, shown in figure 2, was simulated. It consisted of an x-ray source, a \(\frac{\pi}{2}\) phase shift grating G1, an absorption staggered analyzer grating G2 and an image detector. G2 was positioned at the first fraction Talbot distance of G1.

In simulation, the mean energy of x-ray source was designed at 20keV. The periods of the phase grating and the analyzer grating were 4μm and the detector pixel equaled to 10μm. The sample consisted of four different materials which were Polypropylene, Polycarbonate, PMMA-formvar, Mylar respectively. The slice structure of the sample is shown in figure 3 (a). Four colours are used to distinguish different materials mentioned above, whose parameters have been listed in Table 1. The height of the sample, in the direction parallel to the linear grating structures, equaled to 1mm. The slice had been successfully reconstructed by using sinogram of the extracted data from equation (1) and
The comparison of the theoretical and the extracted information using the improved method had also been performed. The comparison of the profiles (f, g) at the positions indicated in (b, d) by solid lines. As it can be seen from figures 3(a, c, e), the reconstructed images show a high coincidence with the original sample structure. Meanwhile, the comparisons of the profiles shown in figure 3(f) and 3(g) also point out that the retrieved information of both absorption and refraction are in good agreement with their theoretical values, which proves the feasibility of the improved acquisition scheme. Although this new acquisition scheme reduces the requirements of source and system stability, however the reverse projection method still only extracts absorption and refraction signals. In the forthcoming works, a new fast information retrieval method may be proposed to exact scattering signal.

4. Conclusion

Table 1. Parameters of materials that make up the sample

| Materials          | Chemical formula | $\delta (10^{-7})$ | $\beta (10^{-10})$ | colour match |
|--------------------|------------------|-------------------|-------------------|--------------|
| Polypropylene      | C$_3$H$_6$       | 5.32936497        | 1.61908931        | acid blue    |
| Polycarbonate      | C$_{10}$H$_{14}$O$_3$ | 6.56665406       | 2.58399607        | yellow       |
| PMMA-formvar       | C$_5$H$_8$O$_2$  | 6.66553376        | 2.85367757        | red          |
| Mylar              | C$_{10}$H$_{14}$O$_4$ | 7.56593067       | 3.39300005        | orange       |

Figure 3. The slice structure of the sample (a), the sinogram of the extracted absorption signals (b) and refraction signals (d) and their slice reconstruction results (c, e). The comparisons of the profiles (f, g) at the positions indicated in (b, d) by the solid lines.
In this manuscript, an improved data acquisition scheme using a staggered grating has been proposed and simulated. In the reverse projection method, the conjugate reverse projections can be acquired in single shot and the strict requirement of the source and system stability can be reduced to some extent. Simulation has been performed to confirm the feasibility of the scheme. Finally, works in the near future may be done to get the scattering signal extracted by a novel method with the advantages of the proposed method.

Acknowledgements
This work was supported by grants from the Major State Basic Research Development Program of China (973 Program) (No.2012CB825804), the PhD Programs Foundation of the Ministry of Education of China (No.2012340213002) and the National Science Foundation of China (No.11275204, No. 11475175, No. 11405175).

References
[1] Pfeiffer F, Weitkamp T, Bunk O and David C, 2006, Nature Physics 2 (4), 258-61.
[2] Momose A, 2003, Optics Express 11 (19), 2303-14.
[3] Pfeiffer F, Kottler C, Bunk O and David C, 2007, Phys. Rev. Lett 98 (10), 108105.
[4] Momose A, Kawamoto S, Koyama I and Koyama Y, 2004, SPIE proceedings Vol. 5535, 352-60.
[5] Takeda T, Momose A, Hirano K, Haraoka S, Watanabe T and Itai Y, 2000, Radiology 214 (1), 298-301.
[6] Snigirev A, Snigireva I, Kohn V, Kuznetsov S and Schelokov I, 1995, Rev. Sci. Instrum 66 (12), 5486-92.
[7] Chapman D, Thomlinson W, Johnston R E, Washburn D, Pisano E, Gmur N, Zhong Z, Menk R, Arfelli F and Sayers D, 1997, Phys. Med. Biol 42 (11), 2015-25.
[8] Zhu P, Zhang K, Wang Z, Liu Y, Liu X, Wu Z, McDonald S A, Marone F and Stampanoni M, 2010, Proc. Natl. Acad. Sci. U S A 107 (31), 13576-81.
[9] Zanette I, Bech M, Pfeiffer F and Weitkamp T, 2011, Applied Physics Letters 98 (9), 094101.
[10] Bevins N, Zambelli J, Li K, Qi Z H and Chen G H, 2012, Medical Physics 39 (1), 424-8.
[11] Huang Z F, Chen Z Q, Zhang L, Kang K J, Ding F, Wang Z T and Ma H Z, 2010, Optics Express 18 (10), 10222-9.
[12] Ge Y, Li K, Garrett J and Chen G H, 2014, Opt. Express 22 (12), 14246-52.
[13] Wu Z et al, 2015, Medical Physics 42 (2), 741-9.
[14] Wu Z et al, 2013, Medical Physics 40 (3).
[15] Weitkamp T, Diaz A, David C, Pfeiffer F, Stampanoni M, Cloetens P and Ziegler E, 2005, Optics Express 13 (16), 6296-304.