A Translation-based Data Acquisition Scheme for Industrial Computed Tomography

Theobald Fuchs, Tobias Schön, Randolf Hanke

Fraunhofer Development Center for X-ray Technology (Fraunhofer EZRT)

A common department of the Fraunhofer Institute for Integrated Circuits (IIS, Erlangen) and the Fraunhofer Institute for Non-destructive Testing (IZFP, Saarbrücken)

Dr.-Mack-Str. 81
90762 Fürth, Germany
Theobald.Fuchs@iis.fraunhofer.de

1. Introduction

Today, X-ray Computed Tomography (CT) is widely used as a tool for industrial non-destructive testing (NDT). There is a manifold of applications in the laboratory as well with inline testing for industrial production control [1, 2]. Although, various CT data acquisition methods have been developed to meet the different applications, all systems are based on a rotation of the object. Alternatively, this can be achieved by rotating the detector and the source of x-rays around the object, but mathematically both methods are equivalent.

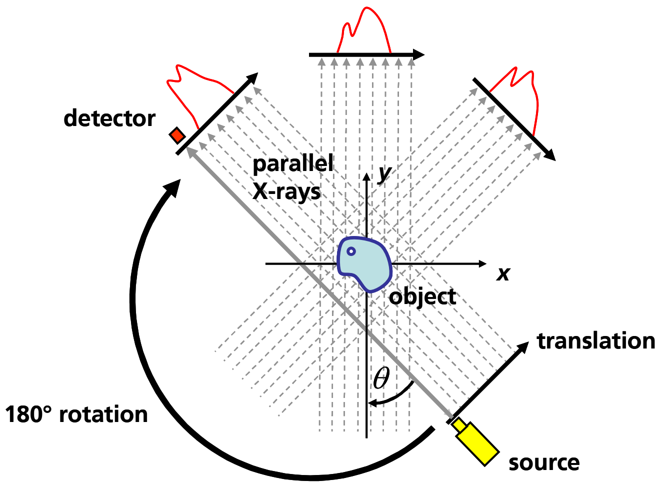

Figure 1: Scheme of the classical parallel beam geometry. The conventional data acquisition for CT imaging requires transmission measurements from at least 180° view angle. In industrial non-destructive testing, usually the X-ray source and the respective detector are fixed and the object is rotated mechanically in-between.

It is important to notice the following fact: although modern CT-systems provide a powerful tool for tasks of NDT and, on the other hand, for medical diagnostics, they all rely on a rotational movement (fig. 1). The CT principle is demonstrated by its most simple realization, the classical translations-rotational data acquisition scheme. Especially to increase the scan speed, today most systems use a fan-beam-type or even cone-beam geometry, and acquire more than one slice during a single rotation by employing multi-row or flat-panel detectors (for a comprehensive introduction into Computed Tomography in general, see e.g. [3]).

A well-known alternative to real 3-D image reconstruction is a technique called digital Tomosynthesis which requires a co-planar movement of X-ray source and detector on each side of the object. While the mechanical costs for the data acquisition during a Tomosynthesis measurement is less compared to the rotational 3-D CT, the resulting image quality is accordingly worse, and most often, Tomosynthesis is not an equivalent substitute for a fully 3-D CT.

Nevertheless, in reality there are numerous objects which are desirable to be inspected by X-ray CT but do not allow for a rotational movement, like e.g. very heavy objects which cannot be accessed from all directions. For instance, such an object could be a pipe, positioned in the corner of a building (fig. 2) or a cable channel located inside a wall.

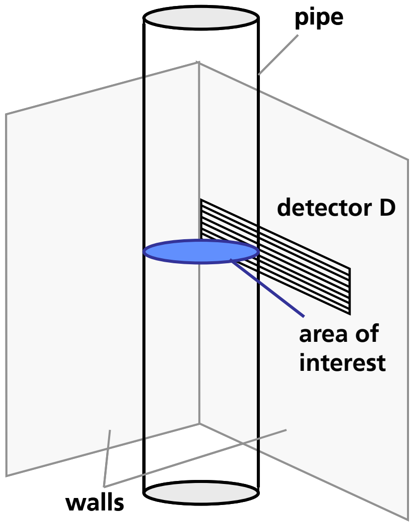

Figure 2: A pipe located in the corner of a room. This object is inaccessible to the conventional 180° view angle data acquisition by rotating an X-ray source and a detector. If there is enough space left between the pipe and the wall to insert a thin linear detector array or a flat panel detector, a Translational CT data acquisition as proposed by us is feasible.

2. Material and Method

Within this contribution, we propose a new data acquisition method called Translational CT [4].

The new technique is based on a linear, translational-only movement of the X-ray source (fig. 3). Given a certain distance of the source x_S to the object, each detector position y defines a different ray angle θ with respect to the object. This allows for acquiring a set of various view angles. Or, seen from a single detector position, each source distance corresponds to another projection. After recording transmission images for a manifold of different source-to-object distances the single data sets are merged by sorting the rays according to their angular orientation. Thereby, the *t*-coordinate describes the shortest distance of the X-ray to the center of the field of measurement (FoM).

The new translational data acquisition scheme is mathematically described in a 2-D plane by the following two equations:

First, there is a relation between the ray angle θ, the source position x_S and the associated detector channel y:

$$\tan\theta = \frac{y}{x_S + 2R_M}.$$

Secondly, the distance t is given as a function of the ray angle and the source position.

$$t_\theta(x_S) = x_S \cdot \sin\theta + R_M \cdot (\sin\theta - \cos\theta).$$

Each single ray is defined by the two parameters, t and θ. Using the two equations, the region within the complete parameter space, which is covered by the translational movement, can be determined.

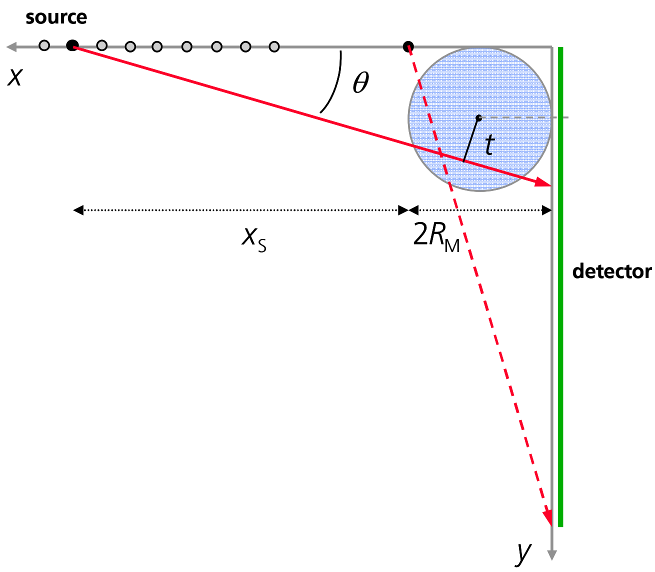

Figure 3: Scheme for data acquisition with linear translation of the source only. The mechanical expense is much less compared to a rotational set-up. The detector (green vertical line) is fixed behind the object. The blue circle (radius R_M) indicates the field of measurement (FoM), which encloses the cross-section of any object therein. As can be seen from the red arrows, the angle of the rays travelling through the object changes as the tube is moved towards or away from the object.

The ray hitting the detector at exactly 90° is referred as the central ray of the x-ray source. The angle of the central ray with respect to the fixed object does not change while the source is translated, thus no additional information is acquired. Deliberately, the central ray is shifted to the edge of the FoM. In consequence, the regions next to the central ray are expected to yield the poorest image quality. Further, it is obvious, that the angular range of rays which can be achieved by translational-only movement is restricted to less than 90° in the limit of an infinitely long detector and the source positioned adjacent to the object ($x_S = 0$).

In order to overcome this intrinsic weakness of the translational approach, we implemented an extended data acquisition scheme employing two translations (fig. 4).

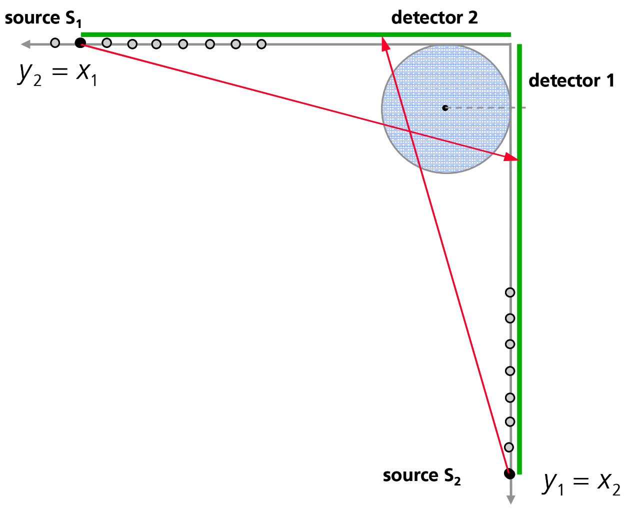

Figure 4: A straight forward extension of the translational method. The translational movement is applied twice with 90° angular offset. The second translation fills the gap of data for view angles between 90° and 180°.

Virtual data were generated for a phantom which resembles a pipe with several details inside, e.g. smaller pipes or cables (fig.°5). During each linear translation of the X-ray source, 200 positions were sampled, with 0.1 spacing relative to the radius of the FoM which is taken as unit: $R_M = 1$. Thus, the source-to-object distance varied between 0 and 19.9, which is equivalent to approximately 10 times the diameter of the object. The virtual detector was simulated with 512 pixel and 0.01 pixel-to-pixel increment. Thus, the linear dimension of the detector is equivalent to approximately 2.5 times the object's diameter. In the case of two linear movements (fig. 4), both were simulated with identical parameters, as described above.

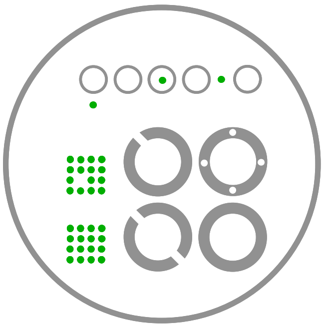

Figure 5: The virtual cross-section examined in the simulation study. The grey circles indicate smaller pipes within a large tube, each showing internal details like holes or slits. The green dots mark cables.

For comparison, a complete set of data were simulated in parallel beam geometry (fig. 1). Explicitly, for each of 200 angular positions within 180° range the FoM (diameter 2 in arbitrary units) the attenuation profile was sampled by 256 parallel rays with a distance of 0.01. The reconstruction was carried out with a complete 180° data set, as well as with reduced angular ranges of 120° and 90° degree in order to compare the degradation of image quality with the respective results for the translational technique.

For image reconstruction a state-of-the art ART (algebraic reconstruction technique) algorithm was used, throughout the whole study [5]. All images have 256 by 256 pixels with 0.01 by 0.01 pixel size relative to the FoM.

3. Results

Fig. 6 shows the reconstruction from a conventional rotation-based data acquisition in parallel beam geometry. The image quality for the complete angular range of 180° is perfect, while rapidly degrading when the range is reduced to 120° and 90°. The angular range utilized can be directly seen from the contour of the wall of the outermost tube.

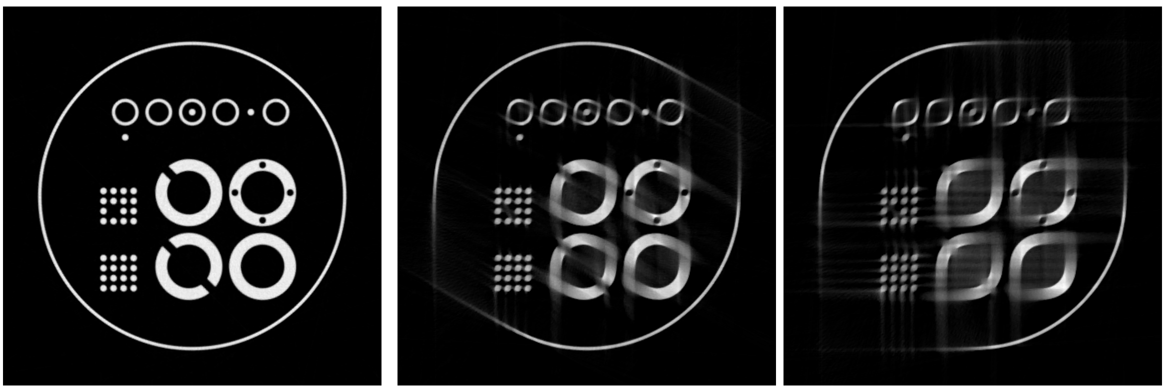

Figure 6: Reconstructions from parallel beam data with an angular range of 180, 120 and 90 degrees, respectively (from left to right).

Fig. 7 shows the respective results of the Translational CT technique with one translation only respectively two translations with 90° angular offset.

Figure 7: Reconstructions from translational data acquired during one translation (0°, left hand side) and during two translations in orthogonal directions (0° and 90°, right hand side)

Obviously, the image quality obtained by a single translation is not sufficient (fig. 7, left hand side). By adding a second translation, with the direction of source movement shifted by 90°, the image quality improved significantly (fig. 7, right hand side). As predicted, the least information can be derived along the central rays (upper left corner). Apart from this, the simulated bundles of four by four cables are depicted clearly (left side), as well as the larger tubes including the slits and holes (bottom right).

At this point, it is necessary to emphasize that the same standard ART reconstruction was applied to all data-sets. Yet there has not been made any adaption or optimization for the translational case. Nevertheless, the results achieved with two translations are already comparable to a rotation about 90° angular range, which is equivalent to 100 projections according to the parameters used in this study.

4. Summary and Outlook

We have shown by simulations that imaging of cross-sections based on CT reconstruction is feasible with a translation type movement of the X-ray source only. Without rotation of the object or the equipment we were able to depict the details within most parts of the section of a large pipe.

The simple way of data acquisition we proposed in this paper should enable 2-D and 3-D imaging of objects, which are commonly thought as not accessible to CT measurements, e.g. pipes in a close distance to other objects or the structure inside of walls or large machinery. An extension to a 3-D translational CT imaging by making use of 2-D flat panel detectors goes without saying.

Of course, our new technique can be used in all cases, including those, where the object is accessible from all sides, but a rotational mechanical set-up is difficult to achieve, e.g. for on-the-field measurements of pipelines, power generators or electrical equipment. Since the translational set-up is simple and straight forward, it can be preferable to the mechanically more complex and expensive rotational set-up. One particularly promising application of the

Translational CT is the 3-D inspection of freight containers, which are typically too large and too heavy to be rotated (fig. 8).

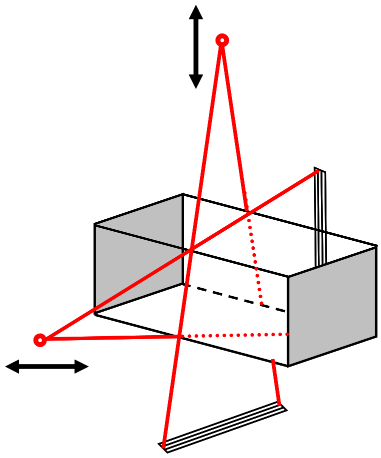

Figure 8: Proposed set-up for 3-D inspection of a freight container by two orthogonal translations of appropriate X-ray sources.

Nevertheless, the image quality achieved by Translational CT method is worse compared to a complete parallel beam data set, measured during a 180° rotation of the object or the X-ray source and the detector, respectively.

Future efforts will be made in improving the quality of the Translational CT reconstructions by exploring several ways:

- taking into account a-priori knowledge about the object
- applying non-equidistant sampling of the source positions
- considering more sophisticated acquisition geometries, e.g. three translations at 0°, 45° and 90°
- optimizing the translational scan parameters in general, i.e. necessary dimensions of the detector and the source travel distance

A thorough mathematical analysis of the translational data acquisition will be published in the near future. This will provide the framework for optimization of the scan parameters. In addition, an experimental validation of the new method is yet to be done.

References

[1] T. Fuchs, T. Schön, R. Hanke, et al., “Progress towards quantitative computed tomography as a tool for industrial inspection,” *European Conference on Materials and Structures in Aerospace 2008*, 26 – 27 May 2008, VDI-Berichte 2028; pp. 425-430

[2] T. Fuchs and R. Hanke, “Task-driven design of X-ray systems for industrial inspection,” *IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC 2008*, Dresden, Germany, 19 - 25 October 2008; pp. 523 - 527

[3] A.C. Kak and M. Slaney, “Principles of Computerized Tomographic Imaging,” IEEE Press, 1988

[4] European patent pending

[5] G. Gordon, et al., “Algebraic reconstruction techniques (ART) for three-dimensional electron microscopy and x-ray photography,” *J. Theoret. Biol.* 29 (1970), pp. 471-481.