Measuring the Distance Between Sphere Centers in Industrial Computed Tomography from Sparse Data

Maximilian Wattenberg [*1,2], Philipp Klein[†2], Maik Stille [‡1], and Thorsten M. Buzug [§1]

[1]Institute of Medical Engineering, Universität zu Lübeck, Germany
[2]YXLON International GmbH, Germany

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Summary: The study introduces a method on how to measure sphere-to-sphere distances regarding the centers of the spheres. Instead of a tomogram, the method uses a ray-tracing approach in order to calculate potential coordinates of sphere centers and a clustering approach in order to remove false positives. The method reduces the number of necessary projection images, which leads to a shorter scan time and faster reconstruction.

1. INTRODUCTION

The use of industrial computed tomography for dimensional measurements, especially in the field of metrology, demands comprehensive knowledge about the X-ray system and the process chain in order to verify that the measurement complies with the measurement specifications. In numerous studies, methods have been developed to evaluate the specific properties of an imaging system, which comprises the X-ray system as well as the process chain of image reconstruction and evaluation [1, 2]. The task of measuring the distances between spheres can be achieved by reconstructing a tomogram from a large number of projection images, applying a nonlinear sphere-fitting algorithm and triangulating the sphere centers [1, 3].

The scan time for acquiring the necessary number of images and the duration for the calculation-intense reconstruction process makes this approach very time consuming. The aim of this study is to calculate the positions of the center of the spheres from a small number of projection images using a ray-tracing and a clustering approach.

2. EXPERIMENTAL METHOD

The reconstruction of the sphere centers is performed in two steps: Calculating potential locations of the sphere centers and removing false positives from the set of all potential locations using a clustering approach. In detail, the potential sphere centers are calculated in multiple reconstruction steps from pairs of projection images. On each of the two projection images a Hough-transformation is performed in order to extract the center and the radius of circular structures in the projection images. The circle centers are converted into object coordinates by taking the system geometry into account. The rays from the X-ray sources to the circle centers, defined by the different projection images, cross the examination volume from different directions. Potential sphere centers are defined by the intersection of two closest lines, whereby the intersection is generalized to the coordinate, which has a smallest distance to the two lines.

The potential sphere centers, constantly calculated for pairs of projection images, are grouped into clusters by the following approach: All the initially calculated centers of the spheres are converted into clusters of their own. All clusters are equipped with an acceptance radius that defines an acceptance volume around the centroids of the clusters. Potential centers of spheres from further reconstruction steps are either added to existing clusters if they lie within the acceptance volume, or transformed into their own clusters. The approach follows the assumption that clusters near real sphere centers contain more elements than false positive clusters.

[*]e-mail: wattenberg@imt.uni-luebeck.de
[†]e-mail: philipp.klein@hbg.yxlon.com
[‡]e-mail: stille@imt.uni-luebeck.de
[§]e-mail: buzug@imt.uni-luebeck.de

Clusters containing less than $p/2$ points, where p is the number of reconstruction steps performed, are removed. A more detailed description of a 2D version of the above described algorithm can be found in [4].

In order to evaluate the described method, a digital phantom of several spheres attached to small pins (compare Fig. 1(a)), was scanned using aRTist [5]. A virtual detector of 750 detector elements in both dimensions with a pixel pitch of 0.233 mm has been used. The focus-detector distance was 2156 mm, the focus-object distance 1078 mm leading to a magnification of 2. Potential sphere centers were calculated from 18 projections and grouped into clusters, with an acceptance radius of the length of one detector element. Thus, false positive clusters were removed by thresholding and the centroids of the remaining clusters were calculated in order to determine the sphere centers. For each sphere center, the Euclidean distance from the reconstructed position to the ideal sphere center positions in the digital model was measured (see Fig. 1(a)).

3. RESULTS

The method introduced in this paper was able to reconstruct the position of the sphere centers from only 18 projection images with an accuracy of 0.13±0.1 dexel (see Fig. 1(b)). Compared to tomogram-based approaches, the proposed method reduces the scan time drastically. Taking into account that the Hough-transformation provides the center of the circles only within an accuracy of one dexel, these are promising results. In future work, the Hough-transformation will be replaced by an algorithm capable of providing the circle centers with sub-pixel accuracy.

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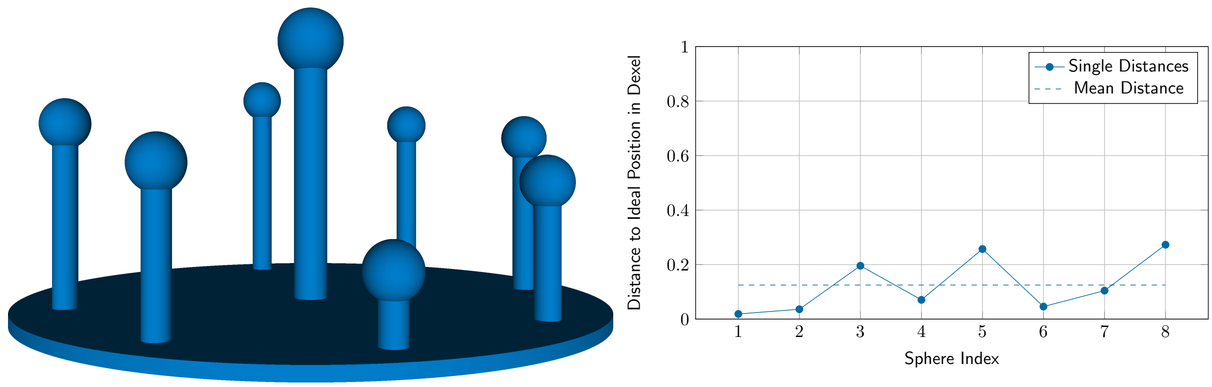

(a) (b)

Figure 1: (a) Model of the digital phantom with eight spheres on top of small pins, arranged in different heights. (b) Euclidean distance from the ideal position to the reconstructed center for each of the spheres.