EXTENDED 3D CT METHOD FOR THE INSPECTION OF LARGE COMPONENTS

M. Simon, C. Sauerwein, and I. Tiseanu
Hans Wälischmiller GmbH, Meersburg, Germany

Abstract: Conventional X-ray 3D computed tomography requires the object to be fully enclosed by the X-ray cone in the horizontal direction. Furthermore, 3D reconstruction algorithms require a 360° rotation of the object. These limitations do not allow the scan of large parts in many cases or lead to a low spatial resolution. In this article we present a new CT system which allows besides conventional 3D CT the scan of large objects by an extended reconstruction method. Region of interest scanning can be performed to achieve a high resolution even in large parts. Examples will be given from the inspection of welds in large objects. The potential for future applications is shown.

Introduction: The acceptance of computed tomography (CT) methods for industrial applications has been significantly increasing during the past years. Especially direct 3D CT systems have been becoming a standard inspection tool for flaw detection as well as for geometrical analysis. State-of-the-art 3D scanners perform fast volumetric scanning and deliver voxel data with an isotropic spatial resolution up to a few microns [1]. These scanners allow the reconstruction of three dimensional structures with a single rotation (Fig. 1). The scan procedure is briefly described as follows: A conical beam from an X-ray source penetrates the investigated object. The attenuated radiation is measured by a large area detector. In order to irradiate the object from all sides, the object rotates in the X-ray cone. During rotation a set of projections is measured and stored. The set of projections is then used to reconstruct the 3D structure of the object.

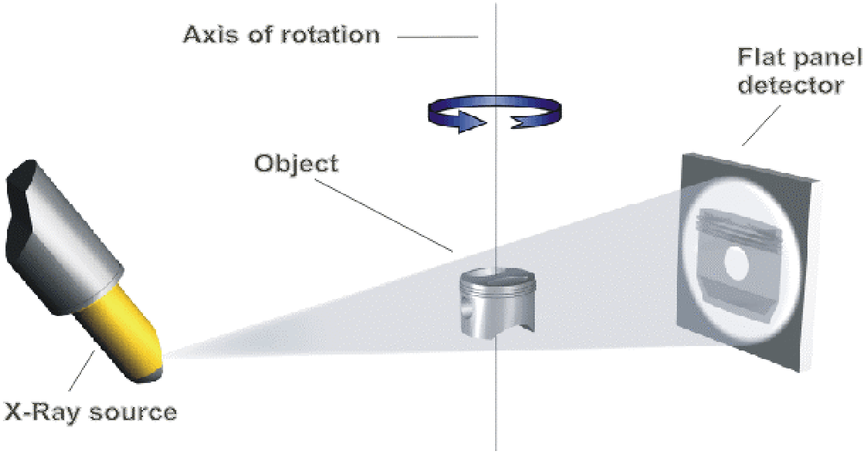

Fig. 1: Principle scheme of 3D cone-beam tomography

In spite if the wide range of applications, the conventional CT reconstruction methods [2,3,4,5] show the following limitations:

Requirements of the conventional CT reconstruction method:	**Limitations for the application:**
Object must be fully enclosed horizontally by the X-ray cone	Limited object size
360° rotation of the object	Limited object size

Sufficient SNR in all projections	Limited material penetration length
All projections need to be within the dynamic range of the detector	Limited asymmetries and density variations

Table 1: Limitations of conventional CT systems

Table 1 shows that conventional CT systems limit the application to objects with small to medium size, which need to be smaller than the size of the X-ray detector. Since a sufficient SNR is required in all projections, the quality of the reconstruction is primarily determined by the "worst case" projections, i.e. the SNR of the projections with the highest penetration length. Therefore, the system limitations do not allow to scan large objects as well as flat objects. If the requirements are not met, artefacts will deteriorate the result.

Another significant limitation of the conventional CT methods is the spatial and the density resolution. In Table 2 the limitations are summarized.

Resolution of the conventional CT reconstruction method:	**Limitations for the application:**
Spatial resolution ≈ object diameter / horizontal detector pixels	Limited spatial resolution
Density resolution = f (dynamic range of detector, dynamic range of object, system linearity)	Limited density resolution

Table 2: Resolution limitations of conventional CT systems

The spatial resolution of conventional high quality state-of-the-art CT scanners is determined approximately by the diameter of a cylinder which fully encloses the object divided by the number of horizontal detector pixels. Hence, the spatial resolution depends primarily on the object size. Therefore, small details in large objects can often not be visualised. Due to the system requirements described in Table 1, the object needs a full rotation in the X-ray cone. In this case the combination of the detector dynamic range as well as the object dynamic range determine the density resolution. System non-linearities further reduce the density resolution.

Results: The above mentioned description of conventional CT methods show severe limitations with regard to possible applications and the achievable resolutions. Many industrial requirements cannot be met by CT because of these limitations. For this reason we developed an extended reconstruction method which overcomes the limitations in two ways:

- Region of interest (ROI) CT
- CT Scan with limited angle

The region of interest CT overcomes the requirement that the object must be fully enclosed horizontally by the X-ray cone. Therefore, large objects can be scanned and the spatial resolution can be increased. The CT scan with limited angle allows to zoom in small areas of large objects. ROI CT and limited angle CT are so far known to produce severe artefacts. However, our approach of reconstructing the data minimize the artefacts to a level which is well acceptable in industrial applications. The result is a 3D reconstruction of sections of large objects with a high resolution. In the following some examples are given to demonstrate the potential of the extended reconstruction method. The examples are reject parts which show some defects. Some of the defects were artificially created in order to demonstrate the recognisability of the inspection method.

Fig. 2 shows a part of a car body. The maximum dimension of the object is approximately 800 mm which is too large for most of the conventional CT scanners. Therefore, we performed our new ROI CT method on the section as indicated in Fig. 2.

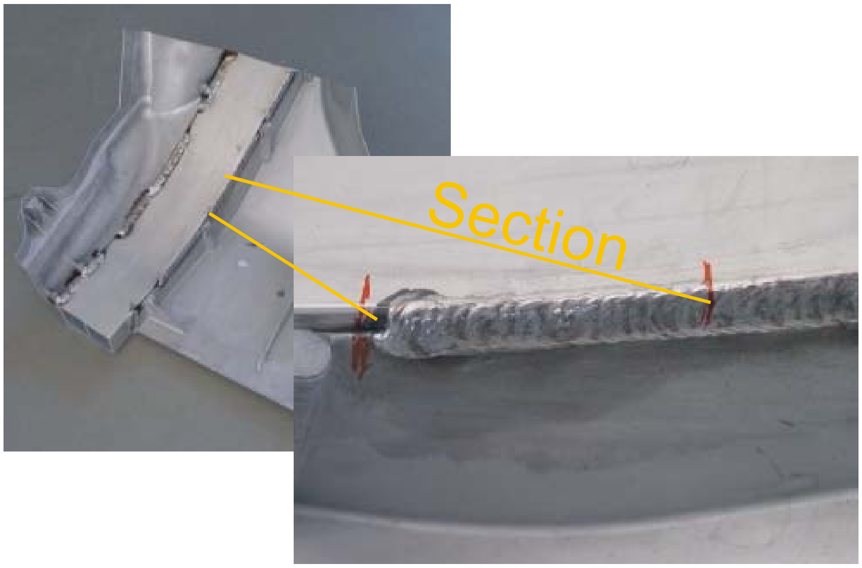

Fig. 2: MIG weld (section) in a car body, object size: 800 mm

The result of our ROI reconstruction with a spatial resolution of 105 µm is shown in Fig. 3. 2D slices are extracted from the 3D data set to visualize the data. The MIG weld is cut in three distances from the edge of the object. All the slices visualise two sheets which are connected by the weld in different degree of root penetration. The above slice shows the beginning of the weld with still a low penetration. The middle slices show some more penetration which is however incomplete. Complete root penetration is visible in the lower slice. However, porosities close to the surface are visible.

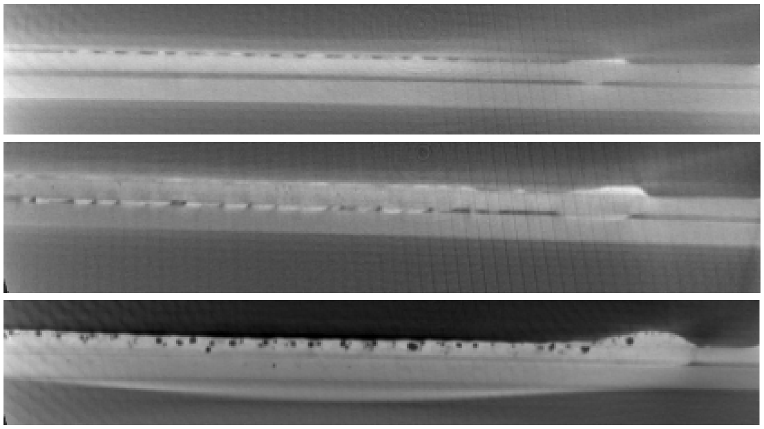

Fig. 3: 2D slices of the MIG weld extracted from the 3D data set

The above shown results demonstrate that all the details necessary for the quality engineers to evaluate the weld are present. The user of our inspection system has full access to the 3D data which allows to cut and visualise in any plane of the reconstructed volume.

In Fig. 4 a part of a car body of a size of 1400 mm is shown. It contains a laser weld which was scanned and reconstructed by our ROI CT reconstruction method.

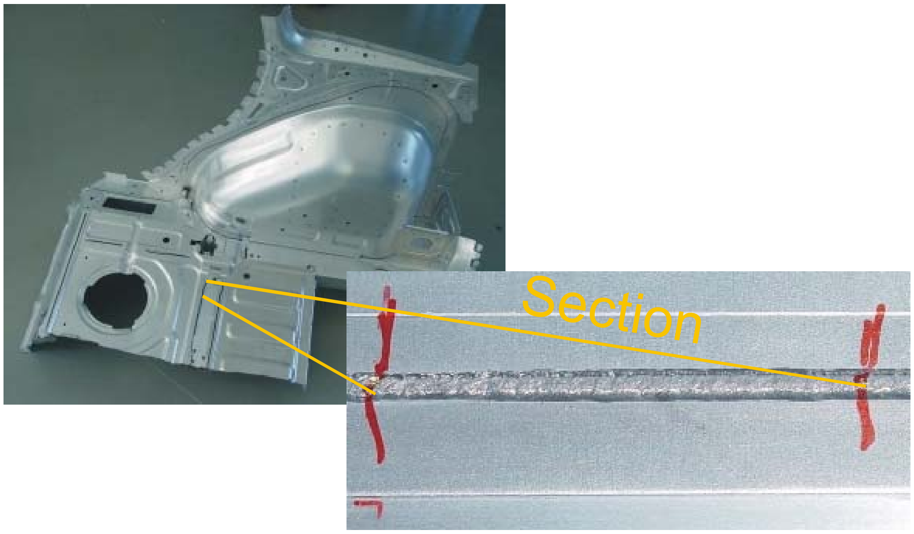

Fig. 4: Laser weld (section) in a car body, object size: 1400 mm

The result of the ROI reconstruction with a spatial resolution of 50µm is shown in Fig. 5. Three slices in different depths are visualised. The lower slice shows the sheets without any welding. The fusion penetration and some porosities in the centre is visible in the middle slice. Finally, the upper slice visualises porosities and a crack with a width of about 200 µm.

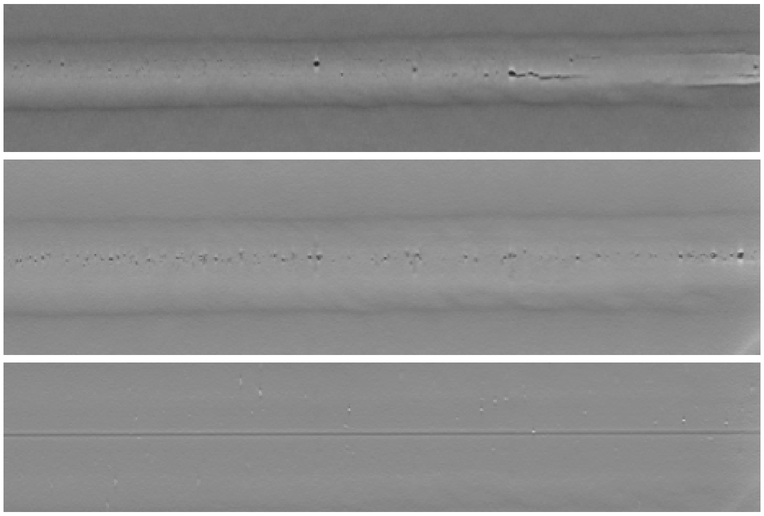

Fig. 5: 2D slices of the Laser weld extracted from the 3D data set

Discussion: Using a conventional CT scanner, an object like shown in Fig. 4 with dimensions of 1400 mm would have a spatial resolution of the order of 1 mm. Small defects of about 200 µm like shown in Fig. 5 would not be visible with such a system. In contrast to this, our new CT system is capable of visualising such small defects in large objects.

In the following the influence of the scan angle in our ROI reconstruction method will be demonstrated.

Fig. 6: ROI CT of a casting part

A section of a casting part (Fig. 6) is scanned and reconstructed using the scan angles 360° (full rotation), 180°, and 135°. Reconstructions of a plane slightly below the surface is shown in Fig. 7. The full rotation reveals flaws and makes the letters well visible (N.B. The small numbers are not very sharp because they are not perfectly aligned in the visible slice). The 180° scan still shows most of the flaws, but small flaws and small details of the letters disappear. Although at 135° even more flaws and details of the letters disappear, most of the flaws are still visible and can be used for a flaw detection. The choice of the scan angle is a trade-of between the gain of voxel size due to a higher magnification of the system and the deterioration of the quality as shown above.

Scan angle: 360° Scan angle: 180° Scan angle: 135°

Fig. 7: Influence of scan angle on reconstruction quality

Conclusions: We introduced our new reconstruction method which overcomes the limits of conventional CT. Namely, it is possible to zoom in large parts and significantly increase the spatial resolution. Examples of welds in large car bodies demonstrated that small defects like porosities and cracks can be easily detected. A ratio of voxel size to object size of more than 1:25000 was shown, which is not possible using conventional state-of-the-art CT reconstruction methods. The method promises a high potential of expanding the industrial utilisation of CT to new areas of application.

References: [1] M. SIMON, C. SAUERWEIN, I. TISEANU, S. BURDAIRON: Multi-Purpose 3D Computed Tomography System. Proceedings of the 8th European Conference on Non-Destructive Testing ECNDT, Barcelona (Spain), 17-21 June 2002.

[2] R.A. BROOKS AND G. DI CHIRO, Principles of Computer Asisted Tomography (CAT) In Radiographic and Radioisotopic Imaging, Phy. Med. Biology, Vol. 21, No 5, pp. 689-732, 1976.

[3] L. A. FELDKAMP, L.C. DAVIS, J.W. KRESS, Practical cone-beam algorithm, J. Opt. Soc. Am. A/Vol. 1, No. 6 1984, pp. 612, 1984.

[4] P. GRANGEAT, 3D reconstructions for diverging X-ray beams, Computer Assisted Radiology, CAR'85, Springer Verlag, Berlin, 1985, pp. 59, 1985.

[5] P. RIZO, P. GRANGEAT, P. SIRE, P. LEMASSON, P. MELENNEC, Comparison of two three-dimensional X-ray cone-beam reconstruction algorithms with circular source trajectories, J. Opt. Soc. Am. A/Vol. 8, No. 10 1991, pp. 1639, 1991.