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Image Registration Combining Digital Radiography and Computer-Tomography Image Data

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Abstract

X-Rays are used as reliable technique for today's quality assurance of safety critical parts, for example in the automotive or in the aerospace industry.

Radiography systems are used to ensure a high throughput in the field of hundred percent testing of a batch. In such systems digital images are acquired by using either flat-panel detectors with a high dynamic range or image intensifiers including nearly noiseless, light-sensitive CCD-sensors inside. The resulting digital X-Ray images are perspective-projections of the three-dimensional density information of the test part onto the two-dimensional picture-plane represented by the dedicated sensor. Due to this projection, structure information and defects may overlap each other. This requires a careful positioning of the test parts to get a penetration of the material as homogeneous as possible. Nevertheless, the three-dimensional spatial information of possible defects is lost in the resulting radiography X-ray image. Also systematic variances of the part (e.g. burr) interfere the defect detection. Therefore sometimes it is hard to decide if possible defects comply to a given specification, i.e. whether a defect in a certain application becomes relevant or not.

Computer-Tomography systems (CT-systems) yield tomograms that are representations of certain slices of the three-dimensional density information of the test parts. Thus the spatial location of the structure of the part or of possible defects is clearly visible. Systematic variances of the part can be excluded from regions that belong to the part directly. But the throughput of test parts is less than on a radiography system, because to compute the tomogram several X-Ray image lines from various views have to be acquired. Using a digital Line-Detector-Array (LDA) and a fan-beam X-Ray source leads to a combination of parallel- and perspective-projection of the three-dimensional density information onto the picture-plane.

This study presents methods for image registration combining digital radiography and computer-tomography image data and is well suited for an appropriate X-Ray testing-system providing radiography images and choosing the layer to compute the tomograms interactively.

Keywords: Digital Radiography, Computer-Tomography (CT), Image-Registration, Parallel- and Perspective-Projection, X-Ray-Testing-System

1. Introduction

Generally, there are two competing techniques for quality assurance of safety critical parts of the automotive or the aerospace industry using X-Rays, namely, the radiography and the Computer-Tomography (CT).

In the radiography two-dimensional image data is generated using a perspective projection mapping the three-dimensional density information onto the picture-plane. Digital images are acquired by using either flat-panel detectors[2] with a high dynamic range or image intensifiers including nearly noiseless, light-sensitive CCD-sensors inside. Without loss of generality, this study assumes that a flat-panel detector will be used. The image intensifier will provide images comparable to those of a flat-panel detector just after a calibration and a distortion correction of its images.

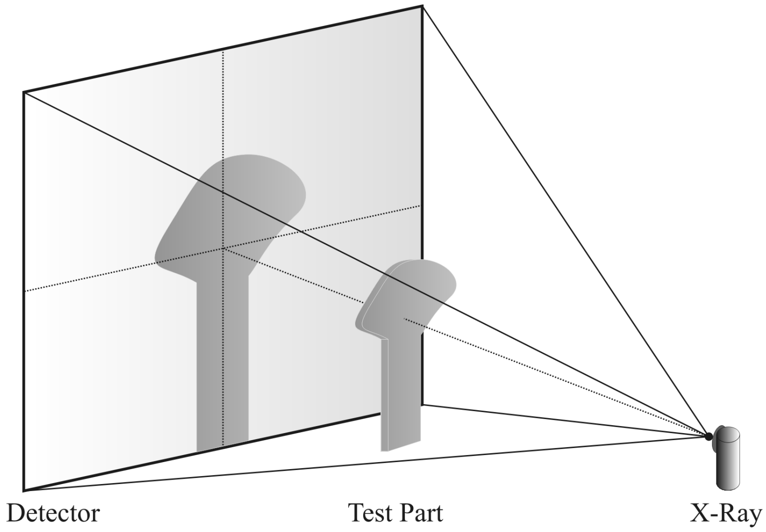

Figure 1: Typical perspective geometry of a radiography system.

Figure 1 depicts the typical perspective geometry, where the three-dimensional test part is mapped onto the two-dimensional picture plane. Due to this projection, structure information and defects may overlap each other, i.e., the three-dimensional spatial information of possible defects is lost in the resulting radiography X-ray image. This requires a careful positioning of the test parts to get a penetration of the material as homogeneous as possible. Also systematic variances of the part (e.g. burr) interfere the defect detection. Therefore sometimes it is hard to decide if possible defects comply to a given specification, i.e. whether a defect in a certain application becomes relevant or not. The aim is always to minimize the number of taken radiography X-ray images to analyze the whole test part, but also to penetrate from appropriate positions through the test part, regarding the thickness or the penetrated density of the material.

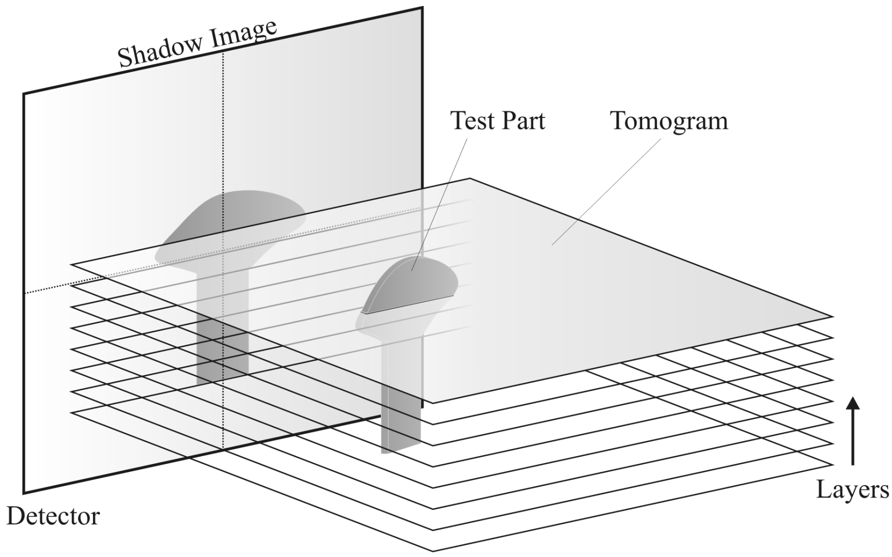

Figure 2: Typical geometry of imaging data of a Computer-Tomography system.

In the Computer-Tomography (CT) slices, called tomograms, on equidistant layers covering the test part partially or even completely are computed from several image lines (see Figure 2). These tomograms are representing the three-dimensional density information. Because this is a one-to-one mapping of the three-dimensional test part, this technique yields not to overlapping defects or structures. Thus the spatial location of the structure of the part or of possible defects is clearly visible. Systematic variances of the part can be excluded from regions that belong to the part directly. Although tomograms may be also computed using radiography images directly, e.g. using a large flat-panel detector, tomograms of superior quality will be generated by using the more cost-efficient line-detector-arrays (LDA) for X-Rays. To acquire the dedicated image lines of a tomogram sequentially the test part will be rotated between a fan-beam X-Ray source and an LDA. Obviously such CT-scan will take longer than acquiring just one radiography image.

Generally, the essential advantage of a radiography system is the significantly higher throughput of test parts in comparison to a CT-system, because less image data has to be acquired and the image data has not to be resampled as it is done for the tomograms.

The essential advantage of a CT-system is the more precisely measurement of the test part and the exact separation of the defects. The spatial location is known exactly and there exists no overlapping of structures and defects in the test part.

The following section takes a closer look at a kind of image data registration of both radiography images and tomograms or even their dedicated shadow images.

2. Image registration of digital X-Ray image data

X-Ray radiography images and tomograms are not comparable directly to each other. Without loss of generality, this study assumes that the spatial orientation of radiography images and tomograms is orthogonal to each other and therefore the vertical position of a found defect in a radiography image is due to the perspective projection unequal to the layer of the tomogram except for the horizontal plane of the X-Ray beam right from the X-Ray source to the center pixel row of the flat-panel detector (cp. Figure 1 and Figure 2). Alternative spatial orientations between radiography images and tomograms may be reduced to the orthogonal case easily.

A combined image acquisition system that provides both types of image data may comprise a cost-effective, normal-sized flat-panel detector for radiography and an LDA for CT image data. First, defects in the test part will be detected by the faster radiography system. The measurement of the exact defect size will be done inside the appropriate tomogram. Therefore the dedicated layer of the tomogram has to be determined from the radiography image directly.

A trivial solution would be to acquire a so-called shadow image with the LDA (see Figure 2). Therefore the LDA and the X-Ray source have to be moved vertically at a constant speed, while acquiring several equidistant image lines sequentially and combining them line-by-line as a two-dimensional image. The shadow image consists of a parallel projection of the test part in vertical direction and a perspective projection in horizontal direction. Thus a visible defect in the shadow image will define the layer of the dedicated tomogram directly by its vertical position.

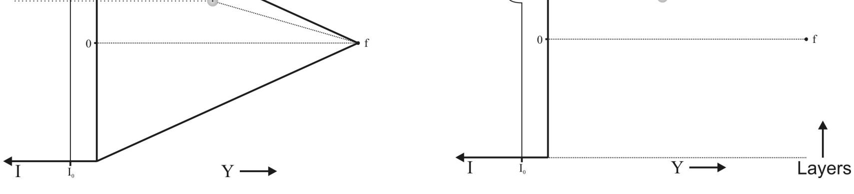

Figure 3: Perspective (left side) and parallel projection (right side) of a defect.

Figure 3 depicts how the different vertical positions of the same defect arise due to perspective and parallel projection. Because of their different perspectives, it would not be easy to assign the found defect in the radiography image to the corresponding defect seen in the shadow image.

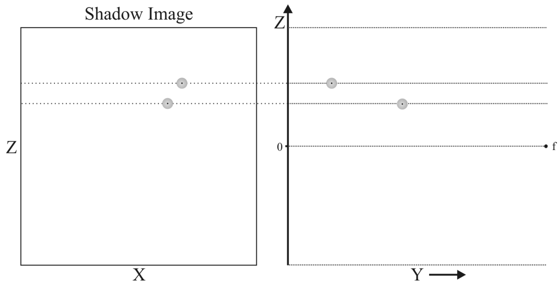

Figure 4: Parallel projection of two defects into an X-Ray shadow image (left).

Moreover separate defects may overlap or not depending on if a perspective or parallel projection has been applied. For example in Figure 4 the two defects are separable in the case of a parallel projection, whereas they may overlap each other in the case of a perspective projection, see Figure 5.

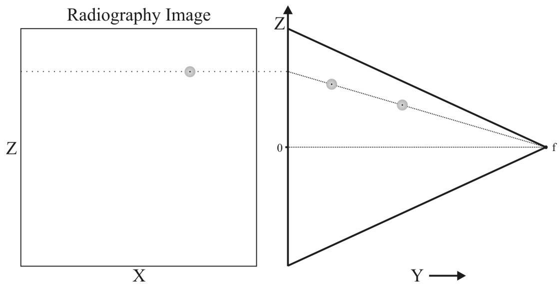

Figure 5: Perspective projection of two defects into an X-Ray radiography image (left).

In the following an approach is presented to determine the layer of the dedicated tomogram directly from the vertical position of the found defect inside the radiography image. The tomogram should slice the center of gravity of the defect. In this approach the X-Ray source and detector system does not need to be moved and the found defect does not need to be found again from a different perspective. Therefore the risk that a certain found defect cannot be separated again in a second image because of overlapping defects or structures is obsolete.

First, a certain defect has to be located and marked in the radiography image. As long as the defect position is not coplanar to the horizontal central plane of the X-Ray source detector system, the vertical position of the defect is not equal to the layer of the dedicated tomogram that slices the center of gravity of the defect.

Thus, the next step is to compute the center of gravity of the found defect in the radiography image. The found defect will become magnified by moving the part in the direction of the magnification axis, i.e. in the direction of the X-Ray source along the central X-Ray beam that hits the detector's central pixel directly. Then a second radiography image is acquired to compute the displacement of the center of gravity because of the movement of the part. From the displacement, the position of the defect in the three-dimensional space can be processed and the position of the layer of the dedicated tomogram can be obtained implicitly.

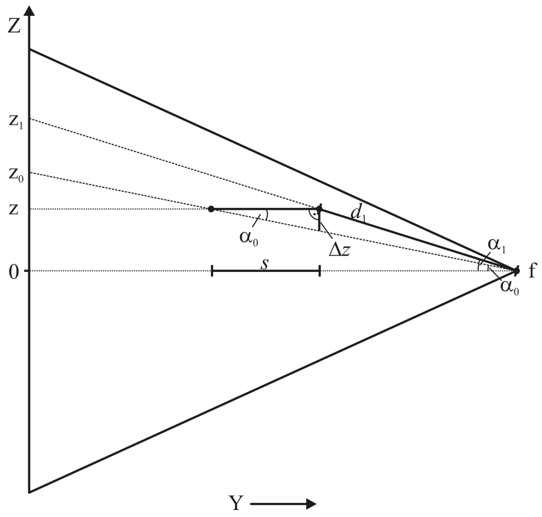

Figure 6: Computing the position z of the layer of the dedicated tomogram using the displacement $\overline{z_0 z_1}$.

Figure 6 illustrates the principle of computing the real vertical position z of the layer of the dedicated tomogram. Here z_0 marks the vertical position of the found defect inside the radiography image of the original perspective whereas z_1 represents the vertical position after the movement or magnification of the part for a certain distance *s* in horizontal direction. The drawing shows the vertical slice along the magnification axis with the flat-panel detector on the left side and the X-Ray source on the right side. From above the following formal context arises:

The distance Δz between the lines ending in z_0 and z_1 is defined by the tangent[1] of α_0 and the movement *s*:

$$\Delta z = \frac{z_0}{\overline{0f}} s ,$$

whereas $\overline{0f}$ is the focus-detector distance (FDD). With the length r_1 of the line ending in z_1

$$r_1 = \sqrt{z_1^2 + \overline{0f}^2}$$

and the intercept theorems[1], the distance d_1 from the focal spot f of the X-Ray source to the moved center of gravity[1] of the found defect is given by

$$d_1 = \frac{\Delta z}{\overline{z_0 z_1}} r_1 .$$

Finally with the sine[1] of α_1 corresponding to the line ending in z_1 and the distance d_1, the vertical position z of the layer of the tomogram is given by

$$z = d_1 \frac{z_1}{r_1}$$

$$= \frac{z_0 z_1}{\overline{z_0 z_1}} \frac{s}{\overline{0f}} .$$

3. Conclusion

This study has shown that is possible to compute the vertical position of the center of gravity of a defect in the three-dimensional space directly from the vertical position of a found defect inside a radiography image, just by moving the test part a little bit along the magnification axis. Thus the layer of the dedicated tomogram slicing the center of gravity of the defect is given implicitly.

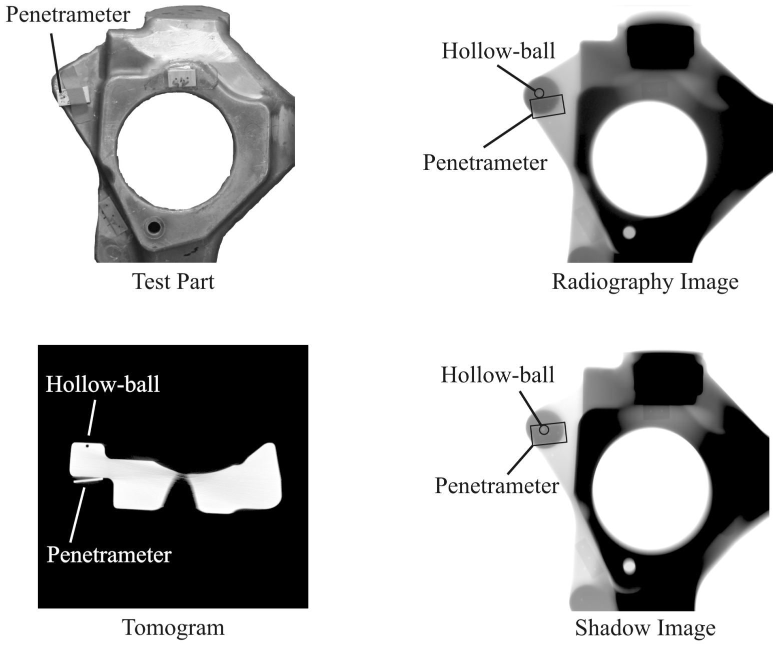

Figure 7: The radiography image and its corresponding shadow image and one tomogram of the test part.

Therefore the time-consuming intermediate step of acquiring a shadow image can be omitted. The shadow image was used to find the corresponding mapping of the defect of the radiography image in the shadow image to derive the layer of the dedicated tomogram. But as the following example will show, this was also an error-prone approach.

Figure 7 depicts a radiography image and its corresponding shadow image. The test part is prepared with hollow-ball calibration-objects[3] and hole-penetrameters. The tomogram slices one of the hollow-balls directly in its center of gravity.

Due to the different perspectives of the radiography and the shadow image, the marked hollow-ball is mapped outside of the marked penetrameter in the radiography image, whereas the hollow-ball is overlapped by the penetrameter in the shadow image. This demonstrates how defects may overlap, so that it will be hard to find the corresponding mappings of a certain defect in both images.

The proposed approach of this study only magnifies the radiography image and therefore also the mapping of the defect, i.e. the shown defect becomes more visible. The perspective is not changed and the center of gravity of the found defect can be determined exactly.

With the resulting transformation formulas from section 2 an appropriate X-Ray testing system including a radiography and CT imaging system is able to compute the layer of the dedicated tomogram slicing the center of gravity of the defect (as it is shown exemplarily in Figure 7) directly from the radiography image.

References

[1] I.N. Bronshtein et al, Handbook of Mathematics, Springer, 5. Edition, 2007

[2] Klaus Bavendiek, Film, CR, and Flat Panel Detectors for the BAM 5 Reference Weld. ASTM Conference, Reno (NV), June 2005

[3] Klaus Bavendiek et al, Prüfkörper für die automatische Überprüfung der Bildqualität und der Messung der Erkennungssicherheit bei ADR Systemen, DGZfP-Jahrestagung 2001, Berlin, Volume 75, 21.-23. May 2001