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Image drift compensation technique for improved measurement accuracy in XCT

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Abstract

Conventional reconstruction algorithms assume only rotational movement of the workpiece with respect to the source-detector assembly. Any undesired mechanical motion contributes to a three-dimensional movement in regards to thereof, typically referred to as image drift. Image drift in X-ray computed tomography (XCT) occurs mainly due to two contributing factors, namely focal spot drift and unwanted mechanical motion. A combination thereof results in three-dimensional image drift of the acquired stack of radiographs over the entire scanning process. As a result, the accuracy of the reconstructed data set is compromised as smearing and blurring of the workpiece degrade the quality of the reconstructed 3D volume. Consequently, the system's measurement accuracy is lowered. Image drift is particularly problematic for high magnification measurements, where small objects, usually containing micro-features, are expected to meet tolerances in the micrometre range. Due to the random behaviour of image drift a compensation method that contemplates all scanning settings/geometrical parameters during a measurement procedure is not possible. Hence, each batch of images must be treated as unique. In this paper, a method that captures image drift, by using stationary reference spheres positioned between the workpiece and the X-ray detector, is presented. By using the first radiograph of the batch as reference image, image drift in all three directions are derived. This is achieved by observing how the reference spheres move throughout the scanning process, in relation to the aforementioned reference image. This method allows image drift compensation by means of a geometrical image transformation. As a result, the segmented surface of the reconstructed volume shows less noise due to the higher quality data set. The greyscale histogram presents better defined peaks and the measurement accuracy is improved, reducing both length and form error.

X-ray computed tomography, image drift, compensation method

1. Introduction

A need for measurement accuracy has become an even higher priority in the manufacturing industry as businesses attempt to grow their trade in a global environment, where competitiveness among companies drives manufacturing tolerances to ever tighter zones.

Amongst several 3D measurement techniques available in the industry that allow manufacturers to meet their needs, X-ray Computed Tomography (X-ray CT) stands out as it allows a full visualization of a complex structure in a non-destructive way [1]. This technique is commonly used for product inspection as it provides product information, such as the looks of its internal structures that otherwise are not accessible in a non-destructive way, that no other measurement technique is nowadays capable of providing.

X-ray CT has been praised not only as an inspection tool but rather as a measurement technique as well. In recent years, researchers have been trying to stablish measurement tracebility in order to make X-ray CT a reliable Coordinate Measuring System (CMS) in the field of dimensional metrology. Accounting for all sources of uncertainty as described in the Guide to the expression of Uncertainty in Measurement (GUM) is however not an easy task due to its vast number of uncertainty contributors [2-3].

Amongst all contributors, image drift has been in recent years studied by several researchers [4-8] in an attempt to understand what is the cause of it, and how it influences measurement uncertainty in X-ray CT. Despite all efforts, image drift contribution to the overall uncertainty has not yet been fully quantified.

In this paper, an attempt to understand how image drift influences the overall data set quality acquired with a Nikon XT H 225 ST machine, and therefore its measurement uncertainty, is shown.

2. Image drift

It has been shown in a previous work [8] that image drift is caused mainly by two components of the X-ray CT system, namely the X-ray gun and the sample holder. The X-ray gun may influence dataset quality in two different ways:

1. Thermal expantion of the X-ray gun; being dependent on how the X-ray gun is assembled to the system. In the past, X-ray guns were fixed by its top extremity to the X-ray cabin, what would allow the gun to expand downwards (towards the ground) moving the focal spot in space during dataset acquisition. However, nowadays the system manufacturer has minimized this issue by changing how the X-ray gun is fixed in the cabin. Now, instead of fixing it by the top extremity, the X-ray gun is assembled to the cabin by the bottom extremety. This change still allows the X-ray gun to thermally expand, however the expansion now happens in the opposite direction. The focal spot in this case does not move during dataset acquisition which eliminates scaling error issues that could otherwise arise due to thermal expansion.
2. Thermal expansion of the target material; due to its low energy efficiency [1] the target material will expand inside

the X-ray gun. This expansion causes the focal spot to drift over time, changing its position during dataset acquisition which leads to scaling error in each individual projection during the acquisition time.

The sample holder on the other hand, can influence the dataset by introducing scaling error problems due to small unwanted motions that may occur during image acquisition.

An apparatus that captures image drift as seen by the object being scanned has been presented in [8]. The object consists of two carbon fiber rods with steel spheres attached to the them. The spheres are positioned as such that they stay located at the bottom corners of the field of view during the whole scan. Figure 1 shows how the apparatus and the object being scanned are displayed on the X-ray detector screen during the scan (B), as well as the overall image drift perceived for that particular scan (C).

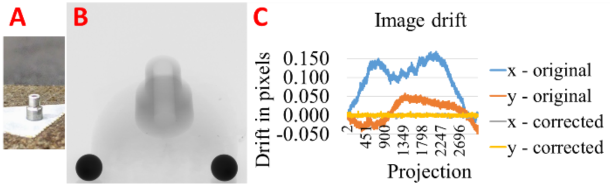

Figure 1. A shows the small step cylinder chosen for experimentation. With such small object a magnification of 40 was achieved. B depicts how the reference steel spheres appear in the X-ray detector together with the step cylinder. C illustrates the original image drift in x and y planes of the detector as well as image drift after all images have been compensated for such.

Image drift correction happens by taking the first projection of the entire dataset as a reference. X and Y center coordinates of the reference spheres are analysed and all consecutive projections are compared against the first one. A difference in X and Y center coordinate position is computed and used for an individual compensation.

3. Results

After the entire dataset has been compensated for image drift during data collection, both dataset, before and after image drift compensation, were reconstructed using CT Pro from Nikon Metrology. Afterwards both datasets were aligned and a comparison taking the unchanged dataset as a reference was made.

Figure 2 illustrates the changes in the step cylinder after the entire stack of projections has been compensated for image drift. It is possible to notice that however small, improvements have happened locally.

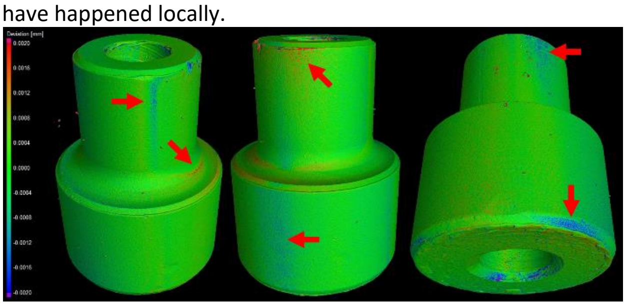

Figure 2. Comparison between the test object before image drift compensation and after. The red arrows depict local improvement of form error deviation.

Figure 3 shows the form error deviation for circles fitted at the mid-section of each cylinder. It is noticeable that although small, improvements in form error have happened. These values represent only the mid-section of each individual cylinder, they change depending on the height these circles are fitted as changes in the overall quality of the dataset have happened locally.

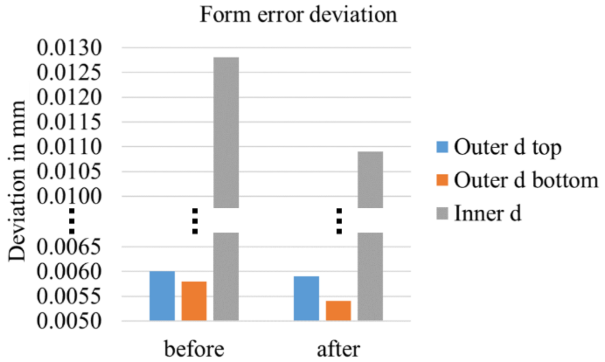

Figure 3. Form error deviation of all 3 diameters of the small step cylinder presented in Figure 2 A before and after image drift correction. All three values were obtained by fitting a circle at the mid-section of each cylinder and evaluating its form error.

5. Conclusions

Image drift is dependent on two factors; magnification and measurement power. As a rule of thumb the higher the magnification, the smaller the component you are measuring will be. This implies that measurement power will be reduced as well, which therefore limits the influence of image drift. On the other hand, the larger the object, the smaller the magnification will be. In this case even with very large measurement power image drift becomes limited. The present research is a first attempt in trying to quantify the influence of image drift on dimensional measurements by X-ray CT. The indication from this work points towards the conclusion that image drift is not so relevant for the overall measurement uncertainty of X-ray CT. Other factors such as system misalignment, and even how the operator handles the dataset seems to be more influencial than image drift. Image drift correction nevertheless still improves dataset quality, but only to a limited extent in this stage of maturity of X-ray CT.

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