
Evaluation of a Micro CT scan system based on digital image correlation profile

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Abstract

The centre of rotation position is a factor that needs to be controlled to avoid artefact in CT scan. A method to evaluate the performance of CT system is needed. The method is developed using x-ray micro-CT system and evaluated based on Digital Image Correlation (DIC). The method of this research is experiment. The multiple radiographs are obtained from scanning object by simulation and experiment. The results show that the ideal DIC profile value of radiograph image from simulation is a constant straight line for every size variation of the object. However, from the experiment, the result show deviation toward $-y$ for every size variation of the object that indicate the shift of COR position in micro-CT system. The result also similar using centre of mass profile value as comparison.

Keywords: CT scan, radiograph, multiple images, digital image correlation

INTRODUCTION

Computed Tomography (CT) is a nondestructive testing technique using x-rays or gamma rays that can visualize the internal structure of objects based on variations in density and atomic composition of the object (Mess, F., *et. al.*, 2003). Its ability to perform these non-destructive tests makes CT an indispensable imaging method in the medical and industrial fields (Buzug, 2008; Chiffre, L., *et.al.*, 2014). In fact, its application has grown widely in various fields such as archeology, geology, astronomy, paleontology, security, etc. (Wu, X., and Schepartz, 2009).

The quality of the reconstructed image results often has interference such as a pattern that does not represent the object being scanned, which is called an artifact (Prince, J.L., dan Links, J.M., 2015). In fact, as a test and inspection tool, the CT system must be able to provide accurate internal image information of objects in order to be interpreted better (Nugroho, W., 2003). Artifacts that appear in the reconstructed image are caused by physical effects (beam hardening, scattering, etc.) and instrumentation effects (geometrical misalignment, heel effect, noise, etc.) (Sun, Y., *et al.*, 2006). Among these factors, geometrical misalignment in CT system instrumentation is the main cause of artifacts in the reconstructed image (Sun, Y., *et al.*, 2006).



The accuracy of Center of Rotation (COR) position is the most important factor in the parameters of geometric to avoid geometrical misalignment (Yang, M., *et al.*, 2013). There will be position shift of COR when the axis rotation of the objects is not on a line with x-ray source and detector. COR position must be controlled because it can cause an artifact in the reconstructed image even though the COR position only shifted by one pixel (Yang, M., *et al.*, 2013; Brunetti and Carlo, 2008). Therefore, evaluation of CT system performance is required, especially for COR position to minimize the artifact in reconstructed image.

The CT system that used for this experiment is X-Ray Micro Computed Tomography that developed at the Department of Physics, Universitas Gadjah Mada, Yogyakarta Indonesia. The Micro CT system evaluation is based on value of DIC. DIC define the correlation between two digital images (Mudassar, A.A. and Butt, S., 2006). DIC measurement goes by tracking a set of pixels that carrying unique grey values (subset) on the main image and reference image using correlation function. The DIC value can be used to compare the Multiple Radiographs (0° - 360°) with the reference image (0°). The DIC value profile is obtained by plotting the DIC values against the object's rotation angle. DIC operations were performed on multiple radiographs for this experiment.

The multiple radiographs that being analysed are the scanned images of aluminium cylinder using X-ray Micro CT system. There are also multiple radiographs from CT simulator software that used for evaluate the Micro CT system. CT simulator software is an ideal CT system that can generate perfect multiple radiograph images. From this point onward, multiple radiograph images from Micro CT system is referred as experimental data, while the multiple radiograph images from CT simulator is referred as simulation data. The result of DIC profile comparison between experiment and simulation to be expected as benchmark for the condition of Micro CT system, especially the position of the Centre of Rotation (COR).

In previous research, there are many method that can be use. The methods are image metrix, geometric measurement, image registration, center of mass measurement, image cross correlation, etc (Ferruci, et al., 2016; Ferruci et al., 2018; Donath, et al., 2006; Yang, et al., 2011; Vo, et al., 2014). It is also necessary to evaluate the Micro CT system using another method to confirm the result from DIC profile. Therefore, measurement of centre of mass is also conduct to the multiple radiography from experiment and simulation.

RESEARCH METHODS

This experiment was conducted at the Department of Physics, Universitas Gadjah Mada. The Micro CT system that used is shown in Figure 1. The voltage that used is 40 kV with the current at 30 mA. The scanning process begin with X-ray source generates X-ray pulses then passing through the object. The X-ray that already attenuated by the object then hit the fluorescent screen which is then converted into visible light and captured by detector or camera. The test object for experiment is aluminum cylinder (Bartscher, et.al, 2008) with even diameter, which are 2 mm, 4mm, and 6mm.

Aluminum cylinder also used with odd diameter which are 2,5mm, 4,5mm, and 6,5mm. The diameter of cylinder then converted to pixel size for simulation; 80 pixels, 160 pixels, and 250 pixels for even diameter; 95 pixels, 185 pixels, and 275 pixels for odd diameter. The object is placed on top of the mount in the Micro CT system. The test object for experiment is aluminum cylinder with even diameter, which are 2 mm, 4mm, and 6mm; and also with odd diameter which are 2,5mm, 4,5mm, and 6,5mm. The odd and even size are related to the Center of Rotation (COR) for simulation.

For simulation, the diameter of cylinder was converted into pixel size which is 80 pixels, 160 pixels, and 250 pixels for even diameter; 95 pixels, 185 pixels, and 275 pixels for odd diameter. When the size of the cylinder is even, the size in pixel also hits even number, which mean the COR position should be in the line between two pixels. On the contrary, when the size of cylinder is odd, the size in pixel also hits odd number, which mean the COR position should be at the pixel in the center. The object is placed on top of the mount in the Micro CT system. The object and the mount are shown in Figure 1.

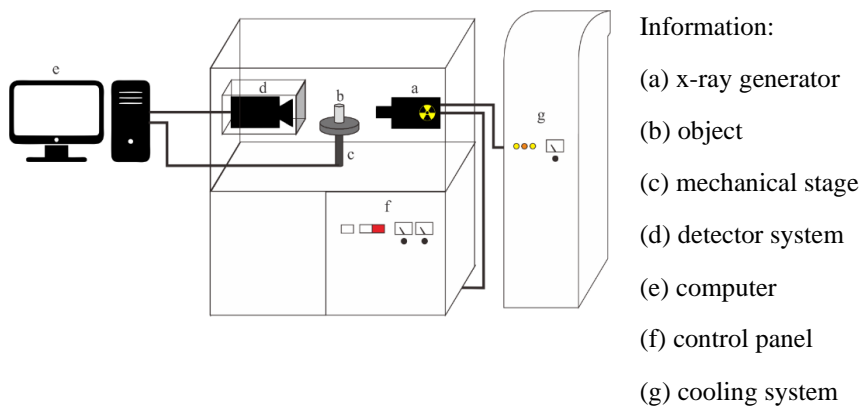


Figure 1. X-ray Micro CT system

Simulation data are obtained from CT simulator software that was created using the Pascal Delphi 2010 programming language. When the simulation is carried out, an x-ray parallel beam is imaginary exposed to the object. Then, partly of the x-ray beam is attenuated, while the rest is transmitted out of the object towards the detector. Once the x-ray beam impinged the detector, then ray sums regarding the shadow of the internal structure of the object are developed. The detector captures the shadow and converts it to the digital image (Figure 3). After running, 360 radiographs are collected from angle of 0° up to 360° at angular interval of 1° (Figure 2).

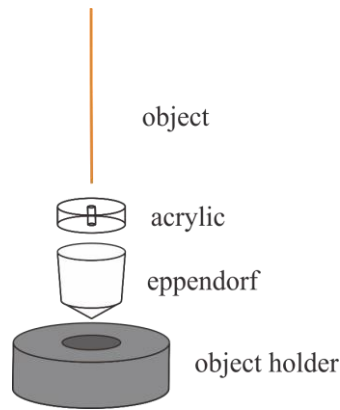


Figure 2. Test object

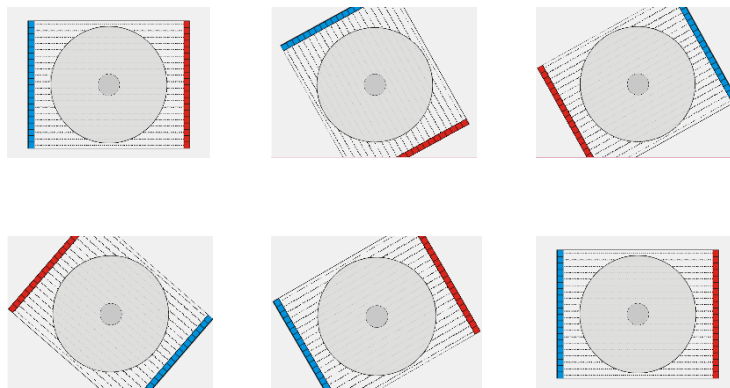


Figure 3. Scanning process of CT simulator

First, the radiograph images from experiment and simulation are processed with ImageJ software. After that, the radiograph images are analyzed using DIC software. DIC measurement is based on tracking correlation function of a group of pixels which have a unique grey value from the test images and a reference image (Zhao et al., 2016; Zhao et al., 2018). The basis of the software is Pearson's Correlation Coefficient equation (Equation 1) with correlation values ranging from -1 to +1 (Harial dan Ramji, 2014; Zhong dan Quan, 2018; Neto, 2013). The multiple radiograph images (0°-359°) are calculated with the radiograph image reference (0°) using DIC to obtain 360 DIC value which then plotted against the rotation angle to get the DIC profile.

$$C = \frac{\sum_{(i,j) \in S} [f(x_i, y_j) - f_m][g(x'_i, y'_j) - g_m]}{\sqrt{\sum_{(i,j) \in S} [f(x_i, y_j) - f_m]^2 \sum_{(i,j) \in S} [g(x'_i, y'_j) - g_m]^2}}$$

The next step is the Centre of Mass (COM) calculation on the multiple radiograph images using Centre of Mass software. COM of image with 2-dimension

function $f(x, y)$ is the center point intensity (x_c, y_c) that satisfies Equation 2. The COM values then plotted against the radiograph images sequence to obtain COM profile.

$$x_c = \frac{\int \int f(x, y) x \, dx dy}{\int \int f(x, y) \, dx dy} \quad y_c = \frac{\int \int f(x, y) y \, dx dy}{\int \int f(x, y) \, dx dy}$$

RESULTS AND DISCUSSION

The multiple radiograph image scanned by CT Simulator is 8-bit image with a resolution of 513x385. The images that obtain are inverted so the grey value of the background is 0 as shown in Figure 5.

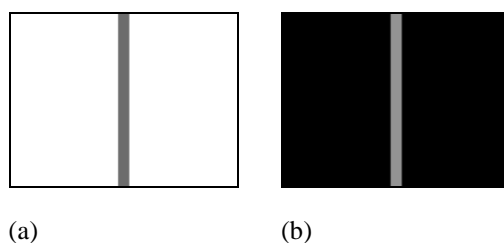


Figure 4. Radiograph image simulation
(a) before *invers* (b) after *invers*

Multiple radiograph image from Micro CT system is 8-bit image with .bmp format. The radiograph image is the scan image of the object from every angle. For every angle of scanning, 3 radiograph images are obtained which were then carried out the average process to produce new image. Furthermore, the image correction process using a dark image and gain image is carried out to reduce noise. Images that have been averaged and corrected using dark and gain images are shown in Figure 5.

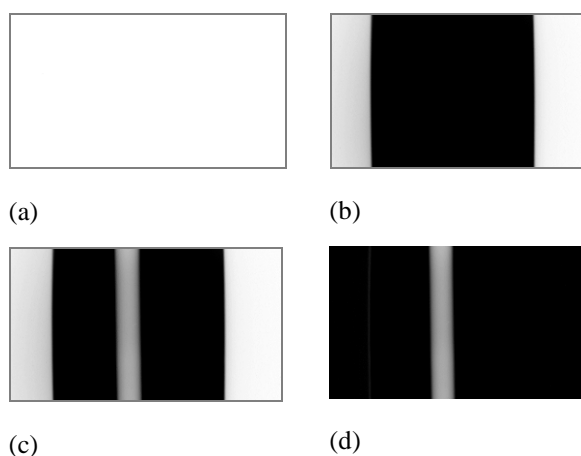


Figure 5. (a) *dark* image (b) *gain* image (c) average image (d) corrected image

The next process is cropping the experiment radiograph image as shown in Figure 6. This process is carried out in order to get an image with 513x385 resolution, same as the simulation image. Contrast and brightness adjustments are also conduct to reduce the noise and clarify the edges using ImageJ as shown in Figure 7.

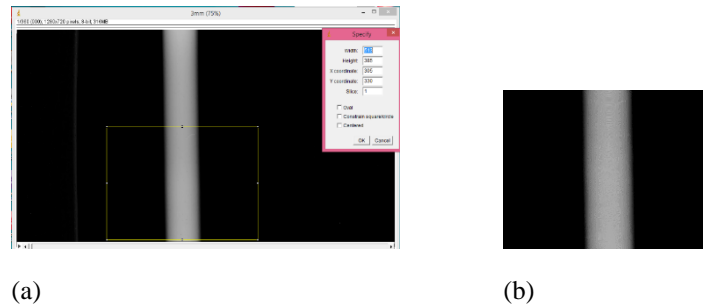


Figure 6. Image crop process

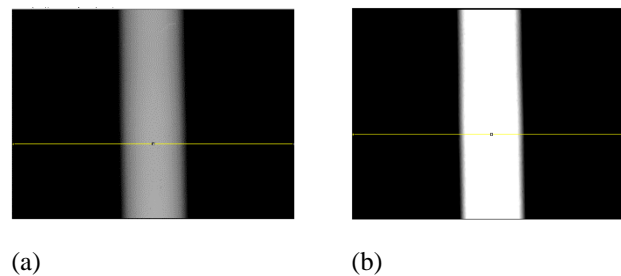


Figure 7. Contrast correction (a) before (b) after

Multiple radiograph images from experiment and simulation that have been processed are then calculated with DIC. The DIC profile of multiple radiograph from experiment are shown in Figure 9 (a), and simulation in Figure 9 (b). It can be seen from Figure 9 (a) that the DIC profile from experiment shows a deviation in every variation of object size when compared with the simulation profile. The larger the object, the smaller the deviation. Sequentially, the lowest DIC value for 80 pixels, 160 pixels, and 250 pixels size are 0.0973, 0.7177 and 0.8055. For 80 pixels size, the DIC profile deviation is larger than the other, because the object is too small and make it difficult to placed vertically in the mount even though using the specially object holder to support it in a straight position. The tilt of the object can be seen on the radiograph image that affect the DIC value.

The multiple radiograph image from simulation is assumed to be the ideal radiograph image, so that the DIC value that obtain should be the same. However, the DIC profile shows a deviation caused by deficiencies of the CT Simulator software. The software cannot determine the centre point of the object if the size is even. The experiment profile has bigger deviation compared with simulation profile as shown in Figure 9.

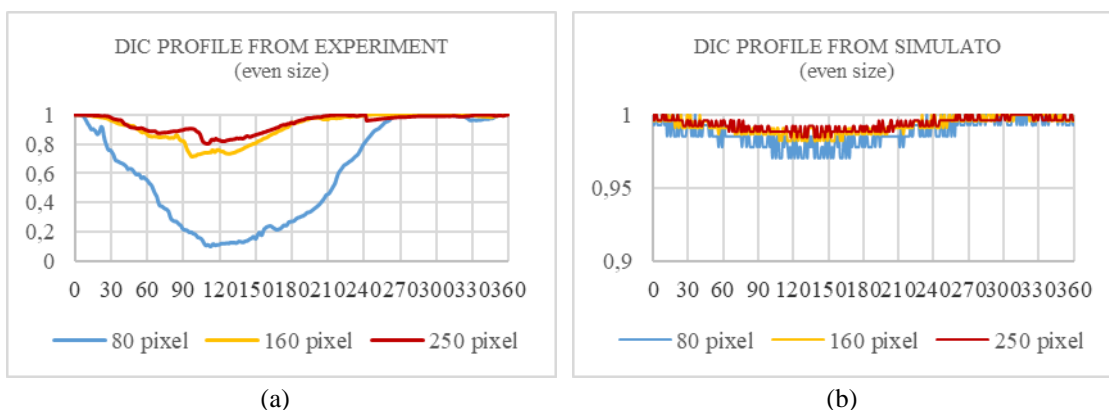


Figure 9. DIC profile of even size object scanned by (a) Micro CT (b) CT Simulator

The result indicates that there is a shift in the COR of the Micro CT system because the multiple radiograph that obtain are not the same for every angle of rotation. The indication of a shift in the COR position is also justify by COM profile. The COM profile by y axis were not shown because it has the same value for every image, which is at position pixel 192. The COM profile are shown in Figure 10. COM profile of multiple radiograph by experiment shows that the COM by x axis for every images are not in the same pixel position. Thus indicate there is a position shift of the object (Donath, et.al., 2006).

When the objects are placed in the COR position, the multiple radiograph images that obtain are the same for every angle, accordingly, the position of COM in x axis or y axis also same for every radiograph image. Figure 10 (b) shows the COM profile of simulation have the same value even though the object has difference size. The COM position for x axis are between pixel 255 to 257 and for y axis is at pixel 192. Based on Equation (2), it is true that the center of mass of image with 513x385 resolution is at pixel (256,192).

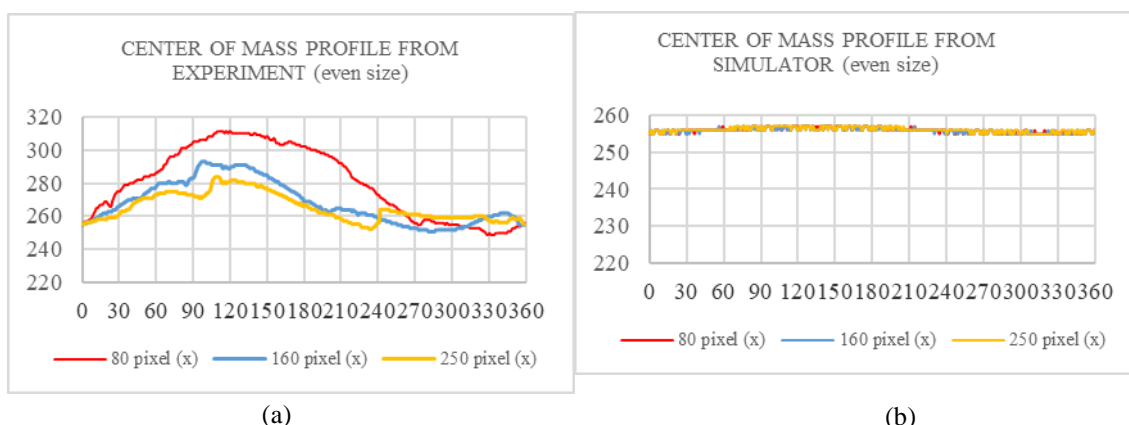


Figure 10. COM profile of multiple radiographs in even size by (a) Micro CT Scan (b) CT simulator

If we look further at the DIC value profile and the resulting center of mass value profile, it can be seen that the farthest deviation in DIC is in the same position when the center of mass has the farthest deviation. At the object size of 80 pixels, 160 pixels and 250 pixels, the farthest deviation of the DIC value profile is located in the 113, 99 and 111 radiograph images. While the farthest deviation of the profile center of mass values is located in the radiograph image 112-117, 99-103 and 111-114. Based on these results, it can be shown that DIC can be used to measure the COR shift of a CT system. The farthest deviation value shows the farthest shift in the object in the scanned multiple radiograph image. The farthest deviation value of the DIC is located on one radiograph image, however, the farthest center of mass deviation is the maximum value of the center of mass on the x-axis which is located on several radiograph images. Based on this, it can be seen that the DIC value profile can indicate the position of the COR shift more precisely than the center of mass.

If we look at the image sequence of multiple radiograph images, the object size is 80 pixels, 160 pixels and 250 pixels displayed by ImageJ software, the initial position of the object on the x-axis lies at 143 pixels, 181 pixels and 225 pixels. The position of the farthest object shift in the three variations of object size is 163 pixels, 211 pixels and 265 pixels, so that the object shift is 20 pixels or 0.5 mm.

Next is the measurement of DIC and COM on objects with odd size variations. The DIC value profile of the experimental multi-radiograph image is shown in Figure 11 (a) while the simulation results are shown in Figure 11 (b). In the experimental results, the DIC value profile shows a deviation when compared with the simulation results. As with the variation in the size of the even test object, the deviation in the DIC value profile of the experimental radiograph image shows a shift in the COR position in the x-ray Micro CT system. In the simulation data, the DIC value is not constant at 1, but ranges from 0.9936 to 1. This is due to the presence of noise in the multiple radiograph images scanned by the CT Simulator.

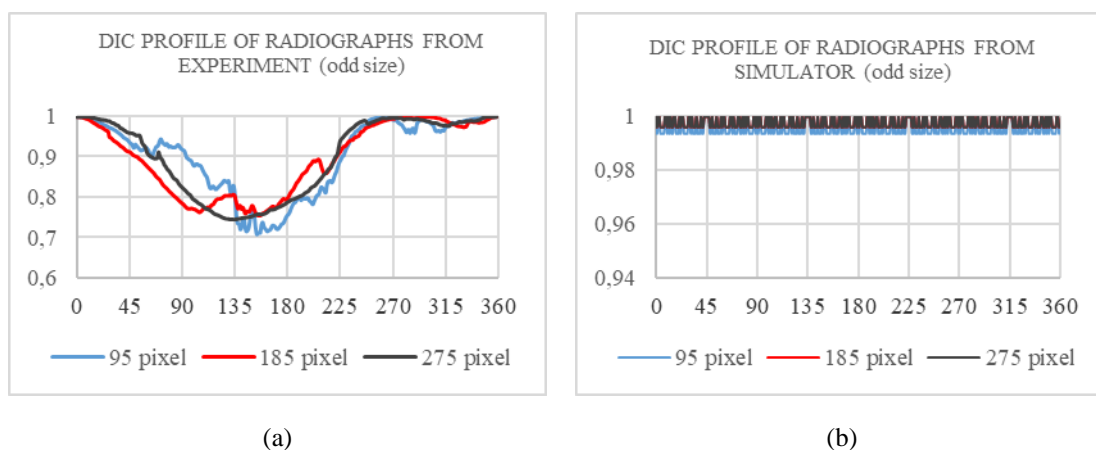


Figure 11. DIC profile of multiple radiographs of odd size object by (a) Micro CT Scan
 (b) CT Simulator

Position shift of COR also shown based on COM profile of radiograph image by experiment in Figure 12 (a). The three sizes variation of the object show the same COM profile but different with the simulation profile at Figure 12 (b). This indicate the

position shift of the object in the radiograph image. The shift of the object in the multiple radiograph image show that the object is not precisely in the COR of the Micro CT system.

Figure 12 (b) shows the COM profile of simulation have the same value even though the object has difference size. The COM position of simulation is at (256, 192). Based on Equation (2), it is true that the centre of mass of image with 513x385 resolution is at pixel (256, 192). Meanwhile, the COM position of the experiment by x axis is between pixel 255 to pixel 296.

If viewed from the relationship between the DIC value and the center of mass profile, at the object size of 95 pixels, 185 pixels and 275 pixels, the farthest deviation of the profile of DIC value is located in the 154, 156 and 137 radiograph images, respectively. While the farthest deviation of the profile of center of mass is located in the 154, 145-165 and 130-144 radiograph images, respectively. X is located at 198 pixels, 168 pixels and 125 pixels. The position of the farthest object shift in the three variations of object size is 218 pixels, 202 pixels and 165 pixels respectively, so the object shift is 20 pixels, 35 pixels and 40 pixels or 0.53 mm, 0, 85 mm and 0.94 mm.

At the object size of 95 pixels, 185 pixels and 275 pixels, the farthest deviation of the DIC value profile is located in the 154, 156 and 137 radiograph images, while the farthest deviation of the profile of the centre of mass values is in the 154, 145-165 and 130-144 radiograph images. Based on the image sequence display of multiple radiograph images displayed by ImageJ software for sizes 95 pixels, 185 pixels and 275 pixels, the initial position of the object on the x-axis lies at 198 pixels, 168 pixels and 125 pixels. The position of the farthest object shift in the three variations of object size are 218 pixels, 202 pixels and 165 pixels. So that the object shift are 20 pixels, 35 pixels and 40 pixels or 0.53 mm, 0, 85 mm and 0.94 mm.

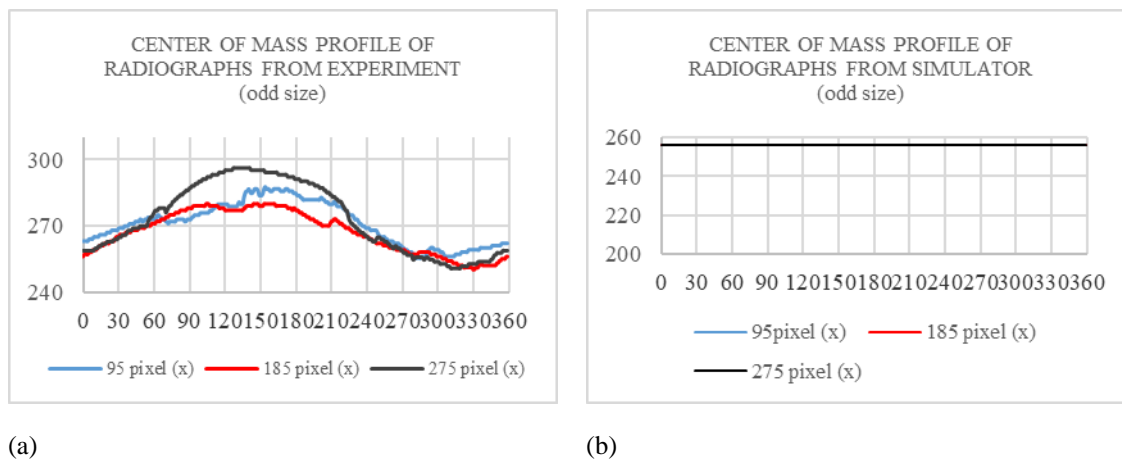


Figure 12. Center of mass profile of odd size object by (a) Micro CT scan (b) CT simulator

Based on the experiment, DIC profile of multiple radiograph images shows deviation to the same direction for every size variation compared to the simulation. Beside that, COM profile of multiple radiograph images by shows deviation to the same direction for every size variation compared to the simulation. Comparing DIC profile

and CoM profile, data above shows that DIC profile is more sensitive than COM profile.

CONCLUSION

Digital Image Correlation (DIC) profile and Center of Mass (COM) profile of multiple radiograph image by experiment shows deviation to the same direction for every size variation compared to their simulation. Based on DIC profile interpretation of multiple radiograph by experiment, there is position shift of Center of Rotation (COR) in the Micro CT system. This conclusion is justified by the differences of DIC profile from experiment with the simulation, and also by the result of Center of Mass (COM) measurement that shows position shift of COM. Shift of COM indicate shift of COR.

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