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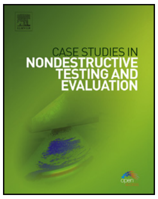

Comparison of medical and industrial X-ray computed tomography for non-destructive testing

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ABSTRACT

Industrial X-ray computed tomography (CT) is an emerging laboratory-based non-destructive testing technique used in a variety of applications for samples ranging from 1 mm to usually 300 mm in diameter. Usually, microCT scanners are used for industrial non-destructive testing due to the superior resolution possible compared to medical CT scanners, but it is not generally known that medical CT scanners can produce reasonable results when high resolution is not needed. As demonstrated in this case study of very dense objects, far shorter scan time is required, compared to conventional laboratory industrial CT systems, consequently being a better solution for applications such as quick scout-scans, high throughput applications and larger objects. This case study makes use of four typical industrial test objects, specifically chosen as candidates which would be expected to be too dense for relatively low-voltage medical scanners. The respective test objects were scanned with both medical and microCT scanners and the results compared for the purpose of industrial non-destructive analysis. The test objects are a steel turbine blade, a titanium casting, a concrete cylinder with aggregate stones and porosity, and a concrete block with metal fiber reinforcement.

1. Introduction

X-ray Computed Tomography (CT) provides a significant improvement in its ability to detect small defects, compared to traditional radiography, hence its growing use in industrial applications [1]. Its use is also widely found in academic research, with recent reviews in food sciences [2], material sciences [3] and geosciences [4]. The use of X-ray CT in the field of metrology and even inline applications using fast scanning industrial CT systems is also rapidly growing, see e.g. [5–7].

Medical CT and industrial CT are based on the same underlying physics principles [8] but differ in system layout and design, due to their different application types. Medical CT has been well described in [9] and compared to industrial CT, it seems in principle not suitable for large dense objects such as steel parts or concrete blocks, due to the limit of 120–130 kV for most such systems. Since higher X-ray voltages are possible with industrial CT systems which allow higher penetrating power, industrial CT or microCT should be improved compared to medical CT scans with respect to image quality for dense objects, due to the improved penetrating power [5]. Industrial CT scanners are usually used for quantitative dimensional analysis [10] while medical CT scanners are optimized for qualitative viewing (image quality of human subjects) and specifically optimized for low dose, while dimensional accuracy is not crucial for medical diagnosis.

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Medical CT has over the years been used for industrial applications, especially before present-day microCT capabilities were available commercially. Especially in the fields of aerospace composites (carbon and glass fiber composite materials) the method has been used widely, see e.g. [11].

However, despite the obvious accuracy and quality advantages of industrial CT systems, the cost of such systems mostly exceed that of medical CT. Industrial CT systems range in price for a basic system capable of 225 kV with micro focus CT capability from 300 000 up to more than 1 000 000 Euros. While lower-cost systems down to 60 000 Euros are available, they are not capable of such high voltages and have other sample size limitations (i.e. Benchtop systems only suitable for small samples). The costs above are also mentioned in a recent perspective on industrial CT [12]. Medical CT systems range in price from 60 000 up to 300 000 Euros for the latest models [13], making them more affordable. Besides purchase price, the scan-time strongly affects the price per scan to the end-user. Typical industrial CT scan times are still 30–60 minutes or more depending on the quality required (see e.g. [14]) while medical CT scanners complete a full scan in 5 seconds (plus a few minutes cool-down time for the system). This difference is significant and allows, e.g., at least 10 samples to be scanned in a medical CT system in the same time as one is scanned in an industrial CT system (with very conservative estimates). Of course, faster industrial scanners are available and in use today dedicated for industrial CT and which are meant for in-line process applications, but these systems are even more costly than the 1 000 000 Euro price mentioned above. The high-throughput and low cost of medical CT is therefore of interest and its use as an alternative or complementary tool is worthy of investigation for some applications.

In this work we test the exact same four large objects on medical and industrial microCT scanners and describe the differences and respective advantages and disadvantages of the two techniques for these type of objects. The choice of objects was made such that these are challenging even for industrial CT with 225 kV micro focus capability, and which are expected to be too dense for low-voltage medical CT. Obviously lower density objects such as glass fiber or carbon fiber composites, wood products, polymers or even lighter metal alloys would result in much improved quality from the medical scans. This is the first direct quantitative comparison between industrial CT and medical CT reported in the scientific literature.

2. Method

Medical CT scans were conducted at Stellenbosch Mediclinic Hospital, with support from Drs Van Wageningen and Partners. The system used was a Siemens Somatom with 130 kV and 250 mA, with scan times usually 5–10 seconds per object, though the system needs cooling down between scans of a few minutes. Voxel resolution for the medical CT scans was fixed at 700 μm. The medical scans were done with standard pre-loaded settings. MicroCT scans were done at the Stellenbosch University CT Facility [15]. The system used was a General Electric V|Tome|X L240, using 220 kV and 180–200 μA, with scan times 1–2 hours for each object. All objects were scanned with 3000 projection images in total, with no averaging or skipping of images. Detector shift was activated to minimize ring artifacts from the center of rotation and the camera gain was set to maximum, while beam filtration was 1.5 mm copper. The voxel resolution of the microCT scans varied from 80–160 μm depending on the object size: steel turbine blade 100 μm; titanium casting 86 μm; concrete cylinder with porosity 80 μm; concrete block with metal fibers 121 μm. Reconstruction was done with beam hardening correction values of 8 or 8.5.

Data was visualized and analyzed using VGStudioMax 2.2 and 3.0 including additional modules for defect detection, orientation analysis and CAD comparison analysis. In the case of the microCT data, a single data filtering was applied to reduce noise and simplify the segmentation process, in the form of an adaptive Gaussian filter. Segmentation was done using a combination of region growing tools and the advanced surface determination function, making use of the selected region as a starting contour for the surface determination. A similar process was applied to the medical CT data. Data set sizes of the medical CT scans in DICOM format totaled 200 MB while the corresponding slice image stack from the microCT scan was approximately 3 GB, excluding raw data which totaled 20 GB.

The four large objects under investigation in this case study are shown in Fig. 1. These are a concrete block with metal fiber reinforcement, a steel turbine blade, a concrete cylinder and a titanium casting that has been subjected to hot isostatic pressing (HIPping).

The concrete with metal fibers is of interest for civil engineering applications and is being researched by a local research group for strengthening of concretes [16]. The steel turbine blade was provided as a test sample from an industrial client: the non-destructive testing of these blades is an ongoing interest in industrial applications due to premature failures causing significant and costly damage and downtime in power plants. In one approach to improve image quality of edge data from such samples, a data fusion approach between microCT data and ultrasonic testing was applied, e.g. [17]. The concrete cylinder sample is similar to, but larger than, that used in a recent multiscale porosity analysis study [18]. The titanium casting was studied before HIPping and reported in a case study previously [11]. The same titanium investment casting process from which this part was made, was also studied before and after HIPping using test rods, therefore not actual complex parts as shown here [19] and is an ongoing research and development effort.