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Artifact removal in Differential Phase Contrast X-ray Computed Tomography

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Value for industry

- X-ray CT can provide measurements of carcass composition and characterize meat samples.
- Heading towards fast on-line CT scanners working in industrial settings calls for robust algorithms to deal with artifacts and non-optimum imaging conditions.
- Research on application of the new CT imaging modalities (phase contrast and dark-field) opens up new opportunities for automated quality control of meat products.
- Development of generic CT image analysis tools for analysis and characterization of animal and food samples during the production cycle is essential for industrial use.
- CT data processing is no less important in getting high quality results than is the X-ray equipment itself.

Background

The novel imaging modalities of X-ray computed tomography (CT) have recently gained increased attention in the area of food science. The additional contrast obtained using so-called phase contrast or dark field imaging (as opposed to absorption) opens up for new applications of CT scanning for food applications, (Nielsen *et al.* 2013). With Differential Phase-Contrast X-ray Computed Tomography (DPC X-ray CT) it becomes possible to achieve greatly enhanced soft-tissue contrast in comparison to conventional attenuation-based scanning.

The superior contrast of soft tissue structures obtained by applying phase contrast CT compared to absorption CT has been documented in a study of pork fat and rind (Jensen *et al.* 2011). The phase measurements can be combined with the traditional absorption measurement to provide multimodal image information, enabling an improved automatic segmentation of the constituents of the meat samples (Einarsdóttir *et al.* 2014). Applications of the new CT modalities also include detection of foreign bodies in food, and distinguishing raw food from frozen.

Why the work is needed

Today most studies are based on synchrotron sources located at major research facilities, but research is ongoing to develop design changes that meet the speed requirement of in vivo imaging applications (Bennett *et al.* 2010). Within the area of farm animal imaging research efforts are carried out within the NEXIM project (NEw X-ray Imaging Modalities for safe and high quality food) funded by the Danish Council for Strategic Research. One ultimate goal is to implement a robust online CT scanner at the cutting line at a pig slaughterhouse. Measurements should result in the spatial distribution of meat, fat and bones and deliver an optimal recipe for automatic cutting of pork middles. With such systems high capacity becomes more important than the directly obtained image resolution and image quality. The handling of image artifacts, the choice of reconstruction methods, and algorithms used for image segmentation and classification can play an especially crucial role for the resulting performance of such a system.

Many kinds of image artifacts are known to impact conventional X-ray tomography. Traditionally these include artifacts due to beam hardening and partial volume effects. In situations where the sampling theorem is far from being satisfied (strong subsampling) ray-like artifacts might also be experienced. The most common type of artifact is the so-called ring artifact. It is most often caused by miscalibrated or defective detector elements, but can for instance also be caused by very small particles trapped on the scintillator. Ring artifacts represent an intrinsic problem of many tomographic images. They are often limited to only some sections of the stack of images and are often more prominent in the center of the sample.

Where optimum imaging conditions are achieved, it has been shown to be feasible to cluster/segment DPC X-ray CT beef samples automatically into intramuscular fat, connective tissue, muscle fibers and water by applying advanced image segmentation methods (Einarsdóttir *et al.* 2014). However, when the image data are corrupted by image artifacts it is very challenging to achieve such a segmentation. In these cases it is desirable to develop image processing routines that can enhance the image quality by suppressing the effects of the artifacts.

The methods used

The measurements were obtained at the Swiss synchrotron radiation light source using a grating interferometric setup (TOMCAT beam line, Swiss Light Source (SLS) at the Paul Scherrer Institute).

We tested our algorithm on a tomogram of a heated beef meat sample that was fit into a 1.5 mL sample tube (Ø = 10 mm). The meat was placed with the fiber direction longitudinal to the tube. (More details are given in Miklos *et al.* 2015). Absorption, dark-field, and phase-contrast modalities were recorded. As the phase-contrast provided better image contrast between the soft tissue components we focused on reducing image artifacts for this modality, but the algorithms will in general also work for the other modalities.

When performing image enhancement of the CT images one can choose to perform post-processing on the reconstructed slices. However, with this approach it can be challenging to deal with the specific causes for the image distortions. If one has access to the original projection data and/or sinograms, more opportunities exist for processing the data as these kinds of data often bear a more direct connection to the cause of the artifacts.

We considered two types of image artifacts: rings and spurious intensity variations. From literature we studied the state-of-the-art for suppression of ring artifacts. Direct spatial filtering on the reconstructed images is one immediate approach to consider. Alternatively, one can transform the image coordinates into the polar domain to take advantage of the circular structure of the artifacts. Methods vary from simple (e.g using median filtering, Boin and Haibel, 2007) to more advanced (e.g using wavelet and Fourier, Münch *et al.* 2009).

Besides the reconstructed data set we also had access to the sinograms of the CT image slices, making it possible to consider implementing the suppression of artifacts at the sinogram-level. Circular or semi-circular structures in the reconstructed CT slices correspond to single stripes or segments of stripes in the sinograms. Therefore, removing rings in the slice is equivalent to removing such features in the sinograms, (Kim *et al.* 2014).

Although we could suppress the ring artifacts on our DPC X-ray CT samples using several of the algorithms suggested in the literature, we felt there was room for improvement. Accordingly, we developed a filtering approach in the frequency domain that detects and remove single stripes and bands of stripes. Our work is based on sparsity decomposition of the signal, where stripes can be detected according to their orientation and scale.

Although we cannot consider the present problem of spurious intensity variations as a case of varying background illumination, we tried various approaches that are often used to suppress variations in the background intensity, e.g. in microscopy applications. We experimented with applying image processing both directly on the reconstructed volume but also in the domain of the sinograms. We achieved the best approach in the sinogram domain by decomposing the signals for each detector into low and high frequency components. From the hypothesis that the variation in intensity levels could be related to slowly time-dependent changes in the detector/scintillator units we removed the low pass component of the recorded detector signals.

The results obtained

The reconstructed volume (Figure 1) was made up of 1400 slices, many highly affected with intensity variations and ring artifacts as shown in Figure 2 and the left image of Figure 3. The result of applying our algorithm for suppressing the rings is shown in the right image of Figure 3. From visual inspection of the zoomed in area in Figure 4 we observed a major improvement. A main feature of our algorithm is its ability to treat both single ring structures as well as thicker bands of rings.

The result of illumination correction is shown in Figure 5. Because we removed the low frequency components of the detector signal we changed the DC levels of the structures. We also lost the contrast of the cylinder wall because of its circular structure with almost constant intensity. On the other hand we kept the high frequency components containing the essential part of the structure. With the basic structure intact and a reduced intensity variation, the task of segmenting the meat structures into its main components was less complicated than by processing the original reconstruction.

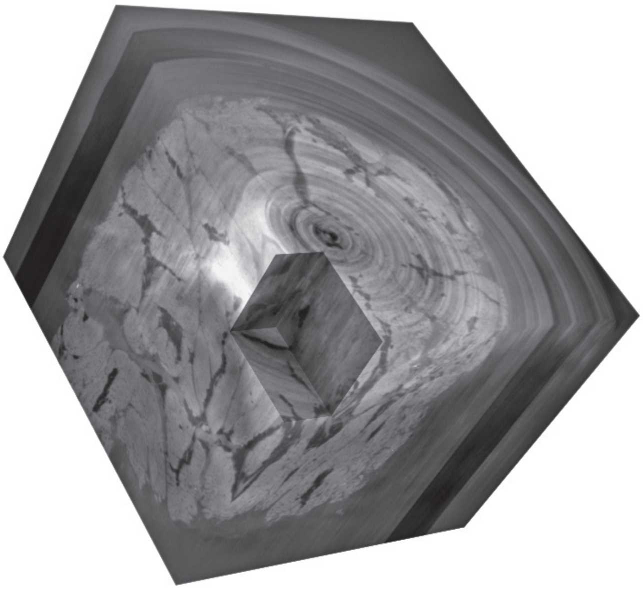

Figure 1. Section of the reconstructed 3D volume of the heated beef sample.

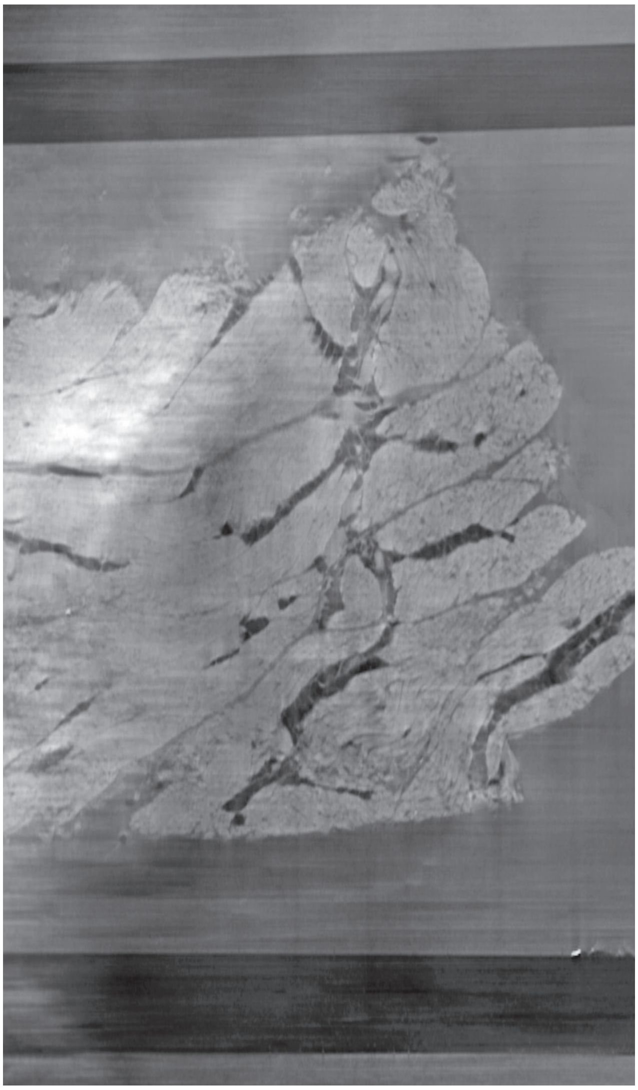

Figure 2. A view of a longitudinal slice through the heated beef sample. Spurious intensity variations occur at different locations.

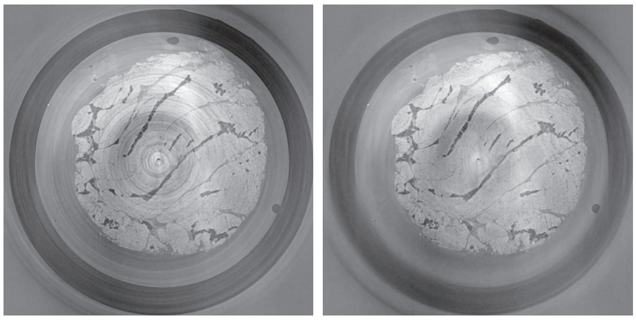

Figure 3. Ring suppression results. Left: a sample contaminated by several ring artifacts. Right: the sample after correction.

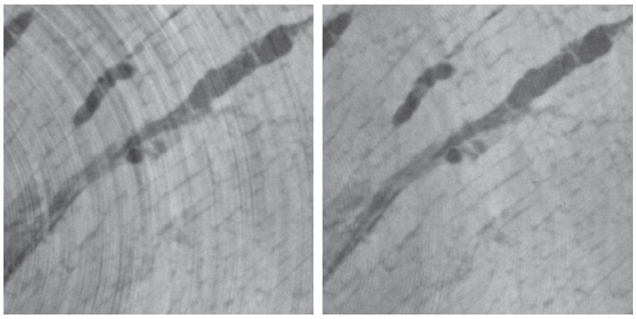

Figure 4. Sections zoomed from Figure 3.

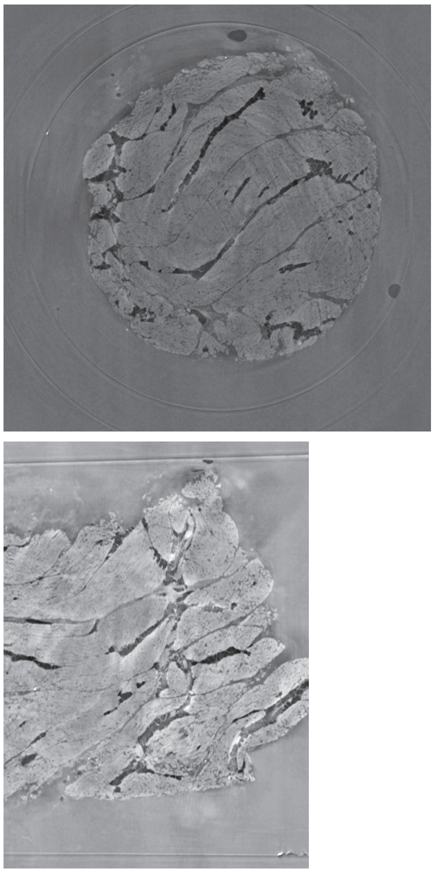

Figure 5. Illumination correction of the sample in Figure 3. Top: the sample after removing the illumination. Bottom: the longitudinal slice in Figure 2 after compensating the intensity variation.

The scientific conclusions

The new imaging modalities of X-ray CT provide many promising applications for use in farm animal imaging (and many other areas of applications). For concrete industrial applications there is a need to develop fast and robust systems. Data processing and image analysis will play a major role here in dealing with non-perfect image conditions and artifacts due to instrumental deficiencies or reconstruction methods based on ideal sample assumptions that can rarely be fulfilled.

Our case study has indicated the need for robust algorithms. Despite the fact that many algorithms have already been suggested for dealing with ring artifacts we were able to come up with new ideas that seem to be of value for severe image impairment caused by ring artifacts. Performing image enhancement is essential in such cases to lay the foundation for applying automated image segmentation.

Our results also illustrate that the development of image processing tools for dealing with CT data is often most beneficial when coupled with an understanding of the image formation process.

The next steps

The algorithm developed will be tested on various tomograms showing ring artifacts. From this we can optimize the details of the algorithm. Also we need to look into parallelization to ensure sufficient speed to deal with the large amount of data.

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