Correction of cupping artifact for cone-beam micro-CT imaging

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Purpose

Images obtained in computed tomography (CT) usually show artifacts due to beam hardening. The origin of these artifacts is the polychromy of the X-ray source and the energy-dependence of attenuation coefficients of tissues, which introduce nonlinearities in the total measured attenuation. Most reconstruction algorithms, however, assume the X-ray source to be monochromatic, which would imply a constant attenuation coefficient and, thus, a linear relationship between attenuation and the thickness of a homogeneous material. In high density heterogeneous materials this results in strike artifacts, while in soft tissue and homogeneous objects –such as those common in micro-CT studies-, a non-uniform depression of image values –the 'cupping' artifact– is predominant.

Different methods to correct these nonlinearities, such as those which linearize attenuation measured on projection data, have been applied in the past in different contexts. Our approach, derived from linearization, is intended for a high resolution, low energy, cone-beam micro-CT, used for in vivo studies on small animals. It focuses on the calculation of a polynomial correction function used to linearize the data and its application to obtain a fast correction that efficiently reduces cupping. No previous reconstructions are required, nor is any knowledge of the X-ray spectrum.

Methods

Different methods of linearization have been described in the literature. This paper presents a fast implementation of a correction algorithm of the projection data based on a linearizing function. Our approach, implemented in IDL, aims at mapping polychromatic projection data obtained from our micro-CT system to monochromatic (i.e., correct) projection data by means of a correction curve of polynomial form. By tackling the nonlinearity produced by beam hardening, the algorithm corrects the cupping artifact.

The correction curve is calculated during a calibration phase, in which projection data of a phantom of known geometry and size is used. In our case, we used a 29 mm radius semi-cylindrical Plexiglas phantom.

In the calibration phase, two different attenuation curves are generated before calculating the correction curve:

• A measured attenuation curve, obtained from the polychromatic projection data of a known phantom (described above). This curve characterises the relationship between the thickness of phantom material along a given ray and the total attenuation registered in the projection data for that ray.

• An ideal attenuation curve: a linear relationship between phantom thickness and total ideal attenuation, that is, the attenuation that would have been registered had the X-ray source been monochromatic.

This linear function is calculated using the mean attenuation coefficient for small material thicknesses, in which beam hardening has hardly any effect.

The measured attenuation curve is then fitted to the ideal attenuation curve by means of a polynomial function, i.e., the correction function.

This curve, obtained once for a given micro-CT system and energy settings, can be stored and used to correct any other projection dataset obtained with that system, provided that the material is homogenous and its density similar to that of the initial calibration phantom.

Fig. 1 Calibration phantom (left) and test phantom (right)

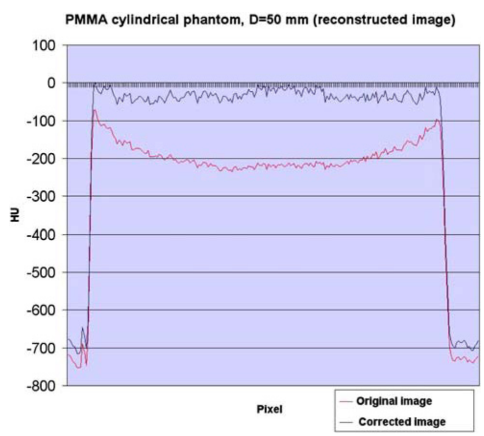

Fig. 2 Efficiency in cupping reduction (reconstructed image)

Corrected projections can then be reconstructed with the usual algorithm. To test the method, a correction function was obtained at the calibration stage using the described phantom and tested for pre-correction on a 50 mm diameter Plexiglas cylindrical phantom, which allowed for greater material thickness along rays Fig 1.

Results

Figure 2 shows a comparison of profiles obtained from both the original image and the corrected image.

The calibration phase took less than 0.5 s and applying the correction curve to a set of 360 420x128 projections of a cylindrical phantom took 12 s. To assess the cupping reduction, we measured on each profile, observing a maximum cupping of 1.1% on the corrected image, as opposed to the 22% cupping on the original image.

Conclusion

We have presented a fast implementation of a correction algorithm, which proves capable of a significant reduction of the cupping artifact in the final reconstructed images of homogenous objects.