Models and Methods for Dynamic Computed Tomography

X-ray computed tomography (CT) is a widely used non-invasive technology that is used to image the internal structure of objects without cutting and breaking them. Since the inception of the first prototype of a CT scanner in 1969, the industrial and medical applications of CT are rapidly increasing. The standard image reconstruction models for X-ray CT are based on the assumption that the object of interest remains stationary during data acquisition in a CT scanner. However, this assumption fails for dynamic CT where the object of interest deforms over time, for example, scanning a beating heart, a pill dissolving in a liquid, etc. The violation of the stationarity assumption can lead to severe motion artifacts in the images reconstructed with the standard image reconstruction models.

The standard reconstruction models that are based on a stationarity assumption can be used for dynamic CT if a sufficient number of projections are acquired within a short period of time such that the object deforms within a tolerable limit. However, limited acquisition time leads to noisy measurements, and X-ray source intensity estimates based on such measurement can be highly uncertain. These uncertainties cause severe and systematic artifacts, known as ring artifacts, which may hide the important information in a reconstructed image. To mitigate this problem, we derive a new convex reconstruction model by carefully modelling the measurement process and by taking uncertainties into account. The experimental results indicate that the model effectively mitigates ring artifacts not only with simulated data, but also with real data sets.

If the stationarity assumption cannot be fulfilled, we can compensate the motion effects by incorporating the motion behaviour of the object of interest into a reconstruction model. In practice, the motion behaviour of the object is unknown. Therefore, we jointly conduct motion estimation and image reconstruction with motion-compensated reconstruction models. These models generally assume that deformations in the object are continuous and smooth over time. Thus, they are not suitable for non-smooth deformations, such as the formation of cracks. In this thesis, we derive a motion model to represent the formation and closing of cracks based on the underlying physics of the crack formation. The proposed model effectively regularizes non-smooth and large deformations along cracks with minimal influence on the nearby regions. The motion-compensated reconstruction models implicitly exploit the redundant motion information present in the measurements acquired over time from different projection angles. Variability in the acquired projections is highly important. In view of this, we propose an interlaced projection scheme to distribute projection views over time based on the family of metallic angles. This scheme is a fixed angular gap scheme, and hence, easy to implement in practice. Moreover, this scheme is suitable for scanning a fast-deforming object. We demonstrate that the proposed interlaced distribution of projection views over time greatly enhances the spatio-temporal resolution of the motion-compensated reconstructions.

In this thesis, our investigations bring forth methodologies which have the potential to achieve high spatio-temporal resolution reconstructions of objects deforming over time. These methodologies pave the way to study the rapid dynamic behaviors, such as the fluid flowing through porous rock and the formation of cracks in drying paint, through tomographic measurements.

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