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Guest-editorial

Computerised tomography performance

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1. Introduction

Generally, computerised tomography (CT) is an X-ray based non-destructive testing method that was developed for medical purposes in the seventies and introduced for industrial applications during the eighties. CT produces maps of the X-ray linear attenuation coefficient of an object's interior; presented either as cross section images (two-dimensional CT) or as volume information (three-dimensional CT). The linear attenuation coefficient is the fraction of X-ray photons absorbed or scattered per unit length as the ray propagates through an object. The linear attenuation coefficient depends on the X-ray photon energy, and both object density and atomic composition.

Most industrial CT systems are equipped with conventional X-ray tubes that produce X-ray photons with an energy distribution, that is, a spectrum. Consequently, the effective linear attenuation coefficient of an object, shown by the CT image, depends on the full energy spectrum, how it changes as it propagates through the object, and how it interacts with the detector. To emphasise contrasts in the final CT image, caused by density or compositional variations in the object investigated, the energy spectrum has to be chosen and shaped with filters in such a way that the differences in effective linear attenuation coefficient increase. However, it is empirically tedious to find optimal CT parameter settings for each individual imaging task, particularly for industrial CT, because of the wide range of object and defect combinations of interest.

2. Objective

The objective of this research has been to increase the accessibility of CT by developing techniques for operators to choose optimal CT-imaging parameters and to predict optimal performance prior to CT inspection. In other words, how should the operator make full use of the equipment performance without time-consuming fine-tuning of the parameter settings? What detectability can be expected for a specific imaging task? How should an imaging equipment be configured to satisfy specific detectability requirements?

The optimal CT parameter settings maximises the information content of the image, that is, maximises the signal-to-noise ratio for a contrasting detail in its surrounding material, for a given exposure time or absorbed dose distribution. Detectability limits are predicted as detectable detail diameter as a function of object diameter. The techniques are valid for CT systems equipped with conventional polyenergetic X-ray sources (X-ray tubes) and partly energy integrating detectors (scintillator screen based detector systems, such as XRIIs) for applications with negligible scattered radiation from the imaged object, such as high resolution CT systems using large geometrical magnifications.

3. Outline of the work

The research was divided into four subparts reported in the five articles presented here [1, 3, 4, 6, 7] together with two previously published articles [2, 5]. The first part includes definition of quality of the CT data in terms of signal-to-noise ratio for detection of a defect in its surrounding material and the relation between CT data quality and the parameters controlling the data-collection. The X-ray related part of the CT data collecting process was modelled for scanning a cylindrical object with a central contrasting detail, from X-ray source to detector entrance screen, for a polyenergetic system [2, 5]. The second part consists of the determination of CT-system characteristics, such as measurement of absolute energy spectra for the X-ray source used and modelling of the transfer of the information from the detector entrance screen through the detector chain to stored CT data [3, 4, 7]. The third part is the model for prediction of detectability limits for contrasting details of arbitrary material in a cylindrical object as a function of object diameter. It requires a model that estimates the absolute image quality in the final CT-image depending on the quality of the CT projection data. This model includes, beside the former two parts, determination and verification of the total unsharpness of the CT system used in terms of the modulation-transfer-function, MTF, as a function of spatial frequency [6]. In the fourth part the model of the CT data collection process has been used to simulate the correction of the CT image artefact called beam hardening that occurs in CT-images when polyenergetic X-ray sources are used [1].

4. Results

The main result from this research is the accurate simulation model of the data collection process that makes it possible to determine optimal operator parameter settings that maximise the detectability for an arbitrary imaging task and predict its detectability limits. The simulation model can also be used to correct for beam hardening artefacts in CT images.

It has been shown that to model the data collection process for CT, a polyenergetic model is needed. It consists of the complete X-ray energy spectra produced by the X-ray source used and a detector response model of how the X-rays impart energy to the detector entrance screen. In this case absolute X-ray spectra were measured using a Compton spectrometer and the detector response was determined using Monte Carlo photon transport simulations.

An astonishing observation is that there are different optimal settings for both different defects in the same object and between different object diameters of the same material. The signal-to-noise ratio for detection of a defect is also very sensitive to the choice of X-ray filter thickness. It is not possible to fully compensate for losses in signal-to-noise ratio from a non-optimal choice of parameter settings by changing others. Increasing the tube potential will never reach maximum signal-to-noise ratio if too thick an X-ray filter was chosen in the first place, for example.

The strategic impacts for this research are:

– Better testing results with optimal parameter settings for each imaging task.

- Shorter testing times when optimal parameter settings are determined prior to inspection with mathematical modelling.
- Better recommendations for choices of equipment for different applications.
- Reduced requirements of qualified operators with fingertip know-how for parameter adjustments.
- Increased confidence in defect size determinations that may prolong component life.

5. General remarks on CT research at Linköping University

The research on CT at Linköping University is done at three co-operating research groups, Division of Engineering Materials, Division of Radiation Physics and Division of Image Processing Lab. At Engineering Materials, industrial CT applications are in focus, particularly research and development of high-resolution applications for materials analysis, such as non-destructive determination of density gradients in powder metallurgy parts and micro crack propagation during thermal cycling of thermal barrier coatings. The main part of the research regarding CT performance and parameter optimisation was carried out here supported by the division of Radiation Physics. The group at Radiation Physics working with computerised tomography and radiography focuses on, among other subjects, the physical image quality for these methods and how it affects detectability. The term 'physical image quality' refers to what happens between the X-ray source, imaged object and detector system. At the Image Processing Lab the tomography research focuses on the CT-image generation, that is, the reconstruction processes. New research efforts concern helical cone-beam scanning as well as fast back-projection techniques. Earlier efforts explored fast direct Fourier methods for reconstruction of 3D volumes from Cone-beam projections.

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