CIVA Computed Tomography Modeling

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Summary

- Context
- From CIVA RT to CIVA CT
- Reconstruction Methods
- Applications
  - Example of Source/detector misalignment
  - Comparison study
Context

- Computed Tomography (CT) is becoming a standard tool in many domains:
  - Material Structure, Earth science, archeology
  - Medical imaging…
- In NDT, tomography is mostly used to provide internal information such as:
  - Inclusions, Cracks, Porosities,
  - Characteristics of the internal structure…
- Experimental CT is a relatively complex process
- Simulation allows to:
  - Test and evaluate the performances of an experimental CT system
  - Optimize the performance by a correct choice of parameters

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From CIVA RT to CIVA CT

- Simulation studies of radiographic inspections with CIVA (since 2007)
  - Simulation of complex parts
  - Direct and scattered radiation
  - Gamma and X sources

Direct radiation + Scattered radiation → Final image
From CIVA RT to CIVA CT

Simulation studies of radiographic inspections with CIVA (since 2007)

- Different types of detectors
- Influential parameters accounting for
- IQI available
Parameters in CT

- « Radiology » parameters
  - Geometry
  - Spectra, intensity, exposure time
  - Filters
  - Processing (for digital radiology)

- Specific « CT » parameters
  - Projections angles/positions
  - Number of projections
  - Reconstruction algorithms
  - Post processing
From CIVA RT to CIVA CT

New Computed Tomography module in CIVA

- CAD object
- Defects
- Civa RT
- Projections
- Reconstruction
- Image Rec.
- Comparison
- ISO Validations
- Data
- Calculation
- Source positions
- Emission cone
- Rotation axis
- Detector
- Object

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Several CT reconstruction algorithms are implemented as plugins:

- Possibility to implement various algorithms on different hardware
- Possibility to compare the different algorithms
Reconstruction methods

- Two algorithms available in the current version:
  - FDK
  - PIXTV

- Possibility to:
  - Define the reconstruction zone
  - Select the number of projections for the reconstruction
Reconstruction with FDK algorithm

FDK (Feldkamp-Davis-Kress) algorithm is a 3D analytic reconstruction method:

- Reconstructs the function $f(x,y,z)$, which is a map of the linear attenuation coefficients of the imaged sample
- It is a three step algorithm of the filtered back-projection type (FBP) for cone-beam data:
  - Weighting: $R_\beta'(p,\zeta) = \frac{D_{SO}}{\sqrt{D_{SO}^2 + \zeta^2 + p^2}} R_\beta(p,\zeta)$
  - Filtering (convolution): $Q_\beta(p,\zeta) = R_\beta'(p,\zeta) * g(p)$
  - Backprojection: $f(x, y, z) = \int_0^{2\pi} \frac{1}{U^2} Q_\beta\left(\frac{x \cos(\beta) + y \sin(\beta)}{U}, \frac{z}{U}\right) d\beta$

where: $U = \frac{D_{SO} + x \sin(\beta) - y \cos(\beta)}{D_{SO}}$
Reconstruction with FDK algorithm

\[ \mu \mapsto f(x, y, z) \]
Reconstruction with PIXTV algorithm

PixTV is an iterative reconstruction algorithm which minimizes the TV (total variation) norm:

- Uses the linear data model for the CT problem
- Projection and image space discretized and represented as a system of equations

\[ p_k = \sum_{l=0}^{N} a_{k,l} \cdot f_l \]

- \( p_k \) is a vector containing the projection data for a ray \( k \),
- \( N = n^2 \) is the total number of pixels,
- \( a \) is the system matrix,
- \( f \) is the image to be reconstructed (reshaped as a vector containing the attenuation values)
Reconstruction with PIXTV algorithm

- Reconstruction → solving a convex optimization problem

$$\min_{f} \frac{\mu}{2} \|Af - p\|^2 + \|f\|_{TV}, \text{s.t. } f \in C$$

- where $\mu$ is a penalty coefficient,
- $A$ represents the system matrix,
- $f$ the CT image, $p$ the projection data (sinogram)
- $C$ a constraint set of possible solutions.

- TV (total variation) regularization
Comparaison FDK vs PIXTV

FDK
- Analytic algorithm: fast
- Implemented on CPU (multithread)
- An important number of projections is needed
- Robust

PIX TV
- Iterative algorithm: slower
- Implemented on GPU
- Less projections are needed
- Many parameters
- Difficult parameter choice ($\mu$)

360 projections
90 projections

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Applications: Example of Source/detector misalignment

Estimate the influence of the rotation axis mispositioning

- Detector:
  - CsI X-ray detector
  - Thickness 300µm ; 1024 x 128 pixels ; 50µm/pixel

- Source to object distance : 50mm
- Source to detector distance : 200mm

- Object :
  - Aluminum cylinder of 10mm in diameter
  - Two sets of aligned holes of diameter 5, 10, 25, 50µm and 50,100, 250 and 500µm and 5 stacked carbon blocks

- 90kV X-ray generator
Estimate the influence of the rotation axis mispositioning

- 360 projections (for all simulations)
- Images are reconstructed with FDK.
- The rotation axis shifted perpendicularly in the horizontal plane with 5, 10, 50 and 100µm
Applications:
source/detector misalignment
Evaluate the influence of the X-ray spot size in a micro-CT configuration

- Same nominal configuration as the previous one

- X-ray spot size has been set to 0, 5, 10, 50 and 200 µm
Applications: Spot size influence
Applications: comparison study

- Evaluate the performance of the presented reconstruction algorithms
  - The X-ray source is a reflection type X-ray generator
  - Acceleration voltage of 100kV
  - Target current of 10mA
  - The sample is a Plexiglas cylinder of 50mm in diameter
  - 15 cylindrical insertions of different materials and densities
Applications: comparison study

Performance of the reconstruction algorithms

- Simulation of 512 projections equally distributed over a full rotation
- Reconstructions of the central plane from the complete set of projections.

- Evaluation for the cases of reconstruction from a lower number of projections: 32 equi-distributed projections.
Conclusion and future works

Full modeling of Computed Tomography in CIVA for:
- Performances estimations
- Optimization of control parameters
- Benchmark of reconstruction algorithms with realistic data

Future works:
- Import and reconstruct experimental data
- Integrate quantitative criteria to enhance benchmarking
- POD module
- Accelerating Monte Carlo computation (scattering photons)
- Development of a specific image processing module
- Implementation of new reconstruction algorithms