FAST INLINE INSPECTION OF APPLES BY A NEURAL NETWORK BASED FILTERED BACKPROJECTION METHOD

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- NN-hFBP
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X-ray Inline Inspection
Problem

- Inspection of fruit:

  - New tomographic reconstruction and analysis methods
  - Inline inspection of food

Requirements:
- Good reconstructions
- Inexpensive
- Fast

Image from: Grant J., Mitcham B., Biasi B. and Chinchio lo S., Late harvest, high CO₂ storage increase internal browning of Fuji apples, California Agriculture 50 (3):26-29, 1996
Inline Inspection

Inspection lines in industry

Radiographic inspection

Source

- No 3D information
- Relative Inexpensive
- Fast
Inline Inspection

Tomographic inspection

- 3D information
- Relative Inexpensive
- Slower
- Artefacts

source

Reconstruction
Inline Inspection

Proposed inspection method

Challenges:

- Fast Inspection
- Good Quality

- 3D information
- Relative Inexpensive
- Rotation
Classic Reconstruction algorithms

- **Fast inspection**
  - Analytical Reconstruction
    - E.g.: FBP
    - Very Fast Reconstruction
    - Slow acquisition
      - Large number of equiangular projections
  - Iterative Reconstruction
    - E.g.: SIRT
    - Slow reconstruction
    - Fast acquisition
      - Small number of projections
    - Incorporate Prior Knowledge

- **Good quality**
  - Fast inspection
  - Good quality

16 vs 128 projections
Inline scanning geometry

Flatpanel Detector

source

Virtual Moving Detector

source
Neural Network Hilbert transform based Filtered Back Projection
NN-FBP

2013: Neural Network FBP

- Parallel beam
- Circular scanning geometry

Contribution

- Fan beam: hFBP
- Inline scanning geometry

**NN-FBP**

Output of a Neural Network:

\[ n_{Q,W,b,b_0}(z) = \sigma_0 \left( \sum_{k=0}^{N_h-1} q_k \sigma_{\text{h}}(w_i \cdot z - b_k) - b_0 \right) \]

Network trained to reconstruct 1 pixel

\[ \sigma = \text{activation function} \]

\[ b = \text{bias} \]

Filters and weights are trained by the neural network
NN-FBP

Output of a Neural Network:

\[ n_{Q,W,b,b_0}(z) = \sigma_0 \left( \sum_{k=0}^{N_h-1} q_k \sigma_h (w_i \cdot z + b_k) - b_0 \right) \]

\[
\text{FBP}_h(x,y) = \sum_{\theta_d \in \Theta} \sum_{\tau_p \in T} h(\tau_p) P_{\theta_d} (x \cos(\theta) + y \sin(\theta) - \tau_p)
\]
Output of a Neural Network:

\[ n_{Q,w,b,b_0}(z) = \sigma_0 \left( \sum_{k=0}^{N_h-1} q_k \sigma_h (w_i \cdot z - b_k) - b_0 \right) \]
Option 1: Convert fan beam to parallel beam

Fan-beam

FBP_{w0} → q_0
FBP_{w1} → q_1
FBP_{w2} → q_2
FBP_{w3} → q_3

Fan Beam → Parallel Beam
Fan-beam

Option 2: Work directly on fan-beam data

Hilbert transform based FBP

Results
Specifications

Data Specifications
- Jonagored apples with defects
- Reconstruction 256 x 256
- Simulate inline projections from available circular projections
- Moving detector 287 pixels
- Data from BIOSYST-MeBios, KU Leuven, Belgium

Network Specifications
- Training: 100 images from 9 apples
- Validation: 10 images from 9 different apples
- Test: 50 images from 5 apples
- 100,000 random pixels for training and 10,000 for validation
- 4 Hidden Nodes
Non-Equiangular Projections

Graphs showing RMSE, Feature SIM, and MAD for different methods as a function of the number of projections.
Reconstructions

Ground Truth

FBP

SIRT

NN-hFBP

16 projections

64 projections

256 projections
Error images

16 projections

<table>
<thead>
<tr>
<th>16 projections</th>
<th>FBP</th>
<th>SIRT</th>
<th>NN-hFBP</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="FBP" alt="Image" /></td>
<td><img src="SIRT" alt="Image" /></td>
<td><img src="NN-hFBP" alt="Image" /></td>
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64 projections

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<tr>
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<td><img src="SIRT" alt="Image" /></td>
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Comparison Projections NN-hFBP

<table>
<thead>
<tr>
<th>#proj</th>
<th>RMSE</th>
<th>RMSE mask</th>
<th>MAD</th>
<th>FSIM</th>
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<tbody>
<tr>
<td></td>
<td>EA</td>
<td>N-EA</td>
<td>EA</td>
<td>N-EA</td>
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<tr>
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<td>16.60</td>
<td>16.66</td>
<td>22.64</td>
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<td>10.65</td>
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<td>14.74</td>
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<td>6.22</td>
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<td>512</td>
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<td>2.11</td>
<td>2.23</td>
<td>2.34</td>
</tr>
</tbody>
</table>

First Indication: Similar quality achieved for both equiangular and non-equiangular projections
Reconstruction time
Conclusions
Conclusions

- Conveyor belt tomography with a fixed source-detector system and an additional object rotation is feasible.
- NN-hFBP outperforms both FBP and SIRT in terms of image quality.
- The reconstruction time of NN-hFBP is an order of magnitude smaller compared to SIRT.
Thank you for your attention

Agency for Innovation by Science and Technology in Flanders (IWT SBO TomFood)