AUTOMATIC MESH SIZE ESTIMATION IN DVC FOR IMAGES OF ISOTROPIC MATERIALS

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• Department: Telecommunication and Information Processing (TELIN)
• Research group: Image Processing and Interpretation (IPI)
• Research topic: My work aims to develop an accurate, robust and efficient Digital volume correlation technique able to cope with high-resolution displacement and image artifacts such as noise, motion artifacts or abrupt material changes (such as fractures).
OUTLINE

• Introduction
• State of the art
• Proposed method
• Experimental setup and dataset
• Results
• Discussion and conclusion
In deformation estimation problem some parameters (as the mesh size) require experience to be set.

My work aims to automate the research of the optimal mesh size.
DIGITAL IMAGE/VOLUME CORRELATION

Digital volume/image correlation (DVC/DIC) is a technique for 3D/2D strain and deformation measurements.

The transformation is based on B-spline.
The transformation is based on B-spline defined on a uniform grid of control points.

\[ u(x, y, z) = \sum_{i,j,w=0}^{n,m,l} P_{i,j,w}N_{i,k}(x)N_{j,q}(y)N_{w,t}(z) \]

- \[ k, q, z : B - Spline \text{ order} \]
- \[ n, m, l : \text{the number of control points} \]
- \[ P - values : \text{form a set of parameters that fix the motion model (control points)} \]
- \[ N_{i,k}, N_{i,q}, N_{w,t} : k\text{-th-degree B-Spline basis functions} \]
- \[ p = n + k + 1. \]

\[ \text{Accuracy in terms of spatial resolution} \]
\[ \text{Computational time} \]

The choice of the grid size/order is usually user dependent.
Self-adapting algorithms are based on the concept of mesh refinement.

- **P-refinement**: mesh elements can transform to higher orders → extra DOFs to faces/edges.
  - Indepedency of the result on the user’s input
  - Improvement of the adaptivity of the mesh in order to obtain a better representation of the deformation field

SELF-ADAPTING ALGORITHMS(2)

Self – adapting algorithms are based on the concept of **mesh refinement**.

- **H-refinement**: mesh elements can change in size
  - Independency of the result on the user’s input
  - Improved performances in image registration
  - Reduction in run-time

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PROPOSED METHOD
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An appropriate mesh initialization brings accurate registration results without going through mesh size refinement process.

- Automatic mesh initialization
  - Start
  - Calculate the initial value of the displacement by using the user-dependent mesh
  - Registration error evaluation
  - Mesh refinement
  - Displacement measurement
  - End

Is the imposed error condition satisfied?

Yes
  - Output

No
  - Mesh refinement
  - Displacement measurement
  - Start

Output
Hypothesis: for images of isotropic materials the optimal mesh size is a function of the image content.

The characteristic size of the most frequently occurring material structure is a good predictor of the optimal mesh size.
PROPOSED METHOD: MESH INITIALIZATION

Step I:
Connected component labeling

Step II:
Study of the characteristic object size distribution

Step III:
Grid size setting

Central slice of µCT image volume
Labeled image

Q. Hu et al., «Fast connected-component labelling in three-dimensional binary images based on iterative recursion», Computer Vision and Image Understanding, 2005.
EXPERIMENTAL SETUP AND DATASET
The experiment was designed for a dual purpose:

• Investigating the impact of different mesh size in the registration result

• The characteristic size of the most occurring material structure is predictive for the optimal mesh size

| Mesh cubic element size | 2^3-2^4-2^5-2^6 | same size of the most occurring object size in the image |
EXPERIMENTAL SETUP: DVC SETTINGS

- **Fixed image volume**
- **Moving image volume**
- **Transform**
- **Warped image volume**
- **Metric**
- **Normalized cross correlation**
- **Optimization step**
- **Adaptive stochastic gradient descent**
- **Converged?**
- **Deformation and strain field**
EXPERIMENTAL DATASET (1)

6 different datasets:

- 3 are from different materials and they exhibit different dynamics:
  - Compression of aluminum foam;
  - Leavening of the bread dough;
  - Expansion of the stone (Lede type) caused by water absorption.

- 3 additional datasets have been created artificially, decreasing the resolution of the previous dataset by a factor of 2 in the 3 dimensions (half resolution).
Acquired by Tescan CoreTOM

Acquired by Environmental Micro-CT scanner (EMCT) @ Ghent University Centre of X-ray Tomography (UGCT)

Acquired by umec

Acquisition time  |  14 min  
No. gantry rotation |  60  
No. projections per rotation |  700  
Total compression per rotation |  +133µm  
Total compression |  +8mm  
Voxel size |  0.02mm  
Volume dimension |  512x512x512  

Acquisition time  |  30 min  
No. gantry rotation |  75  
No. projections per rotation |  800  
Voxel size |  0.02mm  
Volume dimension |  640x640x640  

Acquisition time  |  48 min  
Voxel size |  0.02mm  
Volume dimension |  1014x1014x752  

RESULTS
RESULTS ALUMINUM FOAM (512X512X512)

Z-Y slice of the difference between transformed and reference images at different mesh size.

Mesh size: 8x8x8 (512 voxels)  
NCC: 0.926

Mesh size: 16x16x16 (4096 voxels)  
NCC: 0.948

Mesh size: 32x32x32 (32768 voxels)  
NCC: 0.987

Mesh size: 37x37x37 (50653 voxels)  
NCC: 0.992

Mesh size: 64x64x64 (262144 voxels)  
NCC: 0.992

32^3 – 40^3 : 42.85% of the objects belongs to this interval.
RESULTS LEAVENING DOUGH

Z-Y slice of the difference between transformed and reference images at different mesh size.

Mesh size: 8x8x8 (512 voxels)  
NCC: 0.972

Mesh size: 16x16x16 (4096 voxels)  
NCC: 0.983

Mesh size: 22x22x22 (10648 voxels)  
NCC: 0.995

Mesh size: 32x32x32 (32768 voxels)  
NCC: 0.985

Mesh size: 64x64x64 (262144 voxels)  
NCC: 0.965

$15^3 - 30^3$: 73.33% of the objects belongs to this interval
RESULTS LEDE STONE

Z-Y slice of the difference between transformed and reference images at different mesh size.

Mesh size: 8x8x8 (512 voxels)  
NCC: 0.912

Mesh size: 16x16x16 (4096 voxels)  
NCC: 0.915

Mesh size: 32x32x32 (32768 voxels)  
NCC: 0.989

Mesh size: 40x40x40 (64000 voxels)  
NCC: 0.991

Mesh size: 64x64x64 (262144 voxels)  
NCC: 0.954

24³ – 48³: 75.43% of the objects belongs to this interval.
### RESULTS @ HALF OF THE RESOLUTION

<table>
<thead>
<tr>
<th>Material</th>
<th>Original Resolution</th>
<th>Half Resolution</th>
<th>Best mesh size</th>
<th>NCC</th>
<th>Worst performing mesh size</th>
<th>Best performing mesh size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum foam</td>
<td>512x512x512</td>
<td>256x256x256</td>
<td>37x37x37</td>
<td>0.992</td>
<td>64x64x64</td>
<td>18x18x18</td>
</tr>
<tr>
<td>Leavening bread dough</td>
<td>640x640x640</td>
<td>320x320x320</td>
<td>22x22x22</td>
<td>0.995</td>
<td>64x64x64</td>
<td>11x11x11</td>
</tr>
<tr>
<td>Lede stone</td>
<td>1014x1014x752</td>
<td>256x256x256</td>
<td>40x40x40</td>
<td>0.991</td>
<td>64x64x64</td>
<td>20x20x20</td>
</tr>
</tbody>
</table>

The best performing mesh size for the three dataset has been obtained using our method.

The values of the mesh size that perform bad are still reasonable, but they are not suitable for these dataset.
DISCUSSION AND CONCLUSION
DISCUSSION & CONCLUSION

Our experiments clearly show:

• The result of the DVC is strongly dependent on the mesh size.
• The characteristic size of the most occurring material structure is predictive for the optimal mesh size

PROS:
• The algorithm is able to provide a value to correctly initialize the mesh size, in this way it is possible to avoid the error introduced by the user.
Thanks for your attention!
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