SAND2016-3908C

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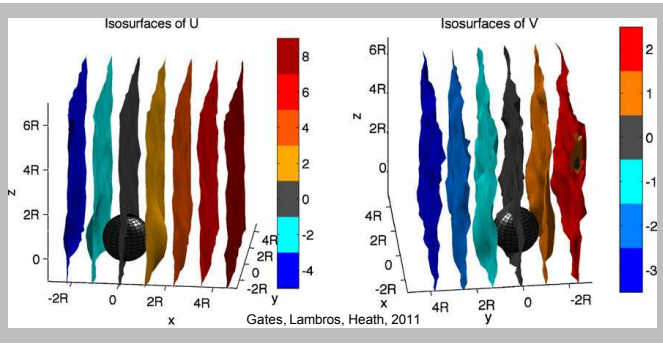

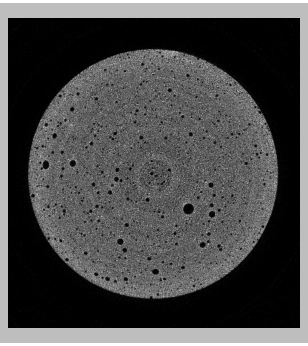

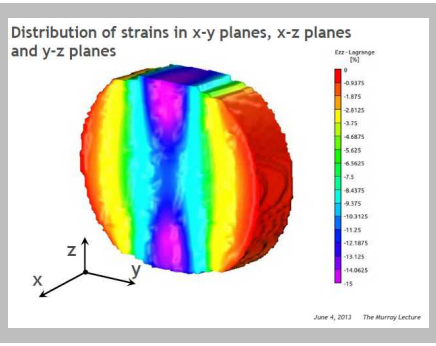

Digital Volume Correlation for Materials Characterization

Enrico Quintana

46th WANTO – JOWOG 39

April 27, 2016

U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration

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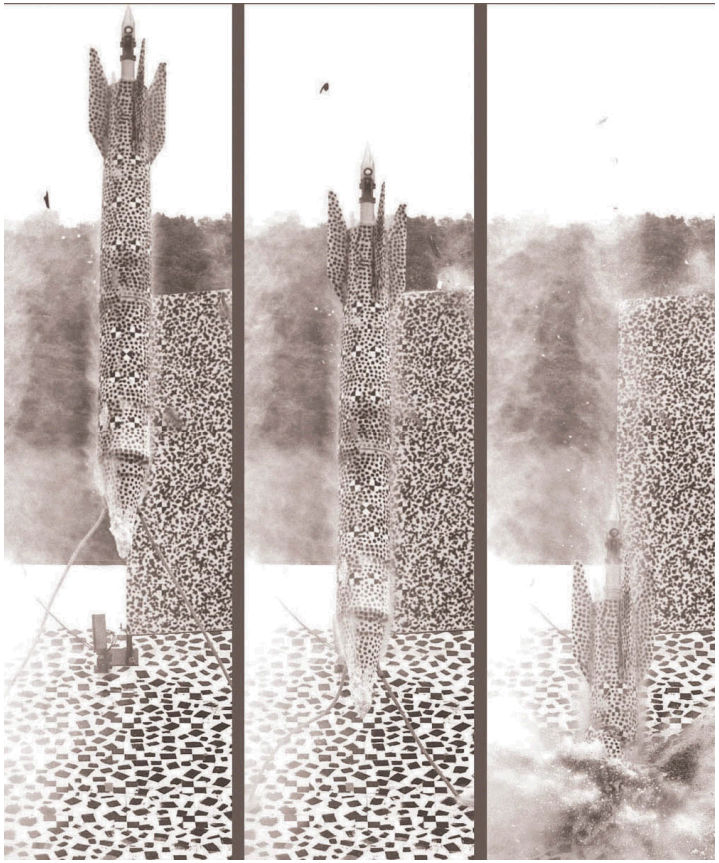
Digital Volume Correlation

- Digital volume correlation (DVC) is based on digital image correlation (DIC)
- DIC (1980's)
  - Optical imaging
  - Speckle pattern
  - 2D and 3D *surface* measurements
- DVC (1999)
  - Computed tomography (CT)
  - Naturally occurring speckle patterns
  - Seed particles for speckle pattern
  - 3D *volumetric* measurements



DIC Images acquired from a recent Sandia National Laboratories test

Ideal DVC Data Requirements

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- Features need to be 3 to 5 voxels in size
- 3 to 4 features in a subset
- Step size ~half subset size
- Minimize noise
- High contrast

Material Applications

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- Foam
- Bone
- Wood
- Composites
- Precipitate Metals
- …Anything with naturally occurring voids, porosity, etc.

DVC Challenges

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- CT scan process
  - Time
  - Spatial Resolution
  - Noise
  - Artifacts
- CT system hardware drift
- No control over naturally occurring structure

CT System Hardware

- Optical table to adequately (and accurately) assemble the CT system
  - Set up to use a variety of x-ray machines and detectors
- Need to finalize part manipulation setup

DVC Hardware

- CT Specific Tensile Stage
  - Allow for compression or tension mounted to CT stage
- Several Options
  - 500N
  - **5kN**
  - 25kN
  - Add-on temperature control

www.deben.co.uk

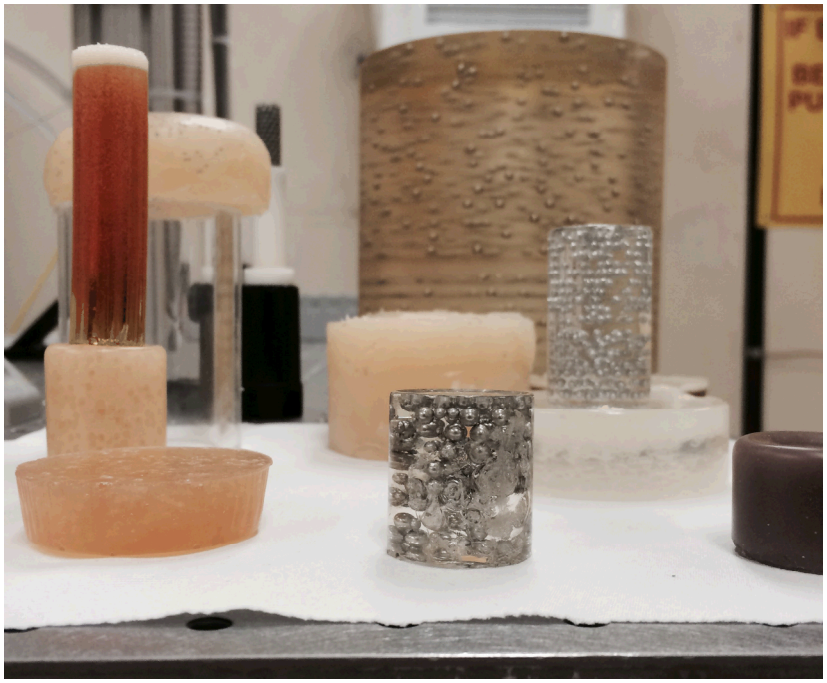
Software Solutions

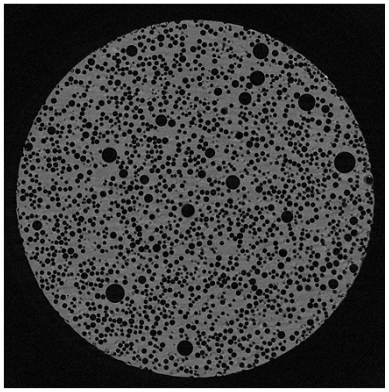
Sandia National Laboratories

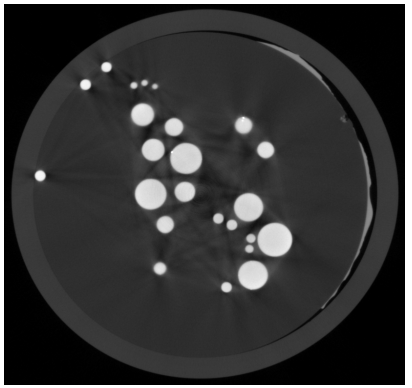
- Commercial Options
  - LaVision
  - Correlated Solutions
- University Efforts
  - LMT-Cachan
  - Illinois-Urbana Champaign
  - Brown

Part Development

- Part Development
  - Materials seeded in epoxy
    - Aluminum spheres
    - Plastic spheres
    - Glass Micro Balloons
  - Foams







Initial CT Scans

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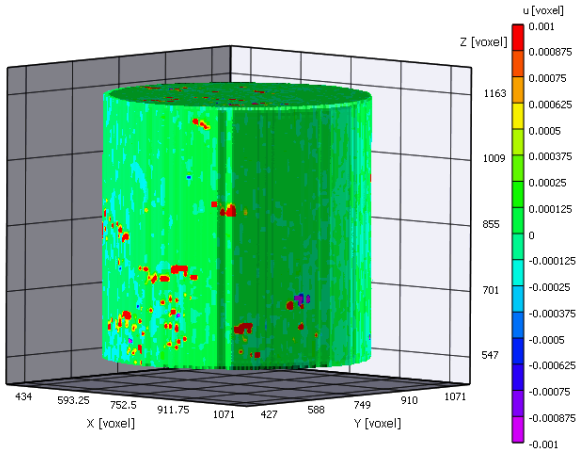
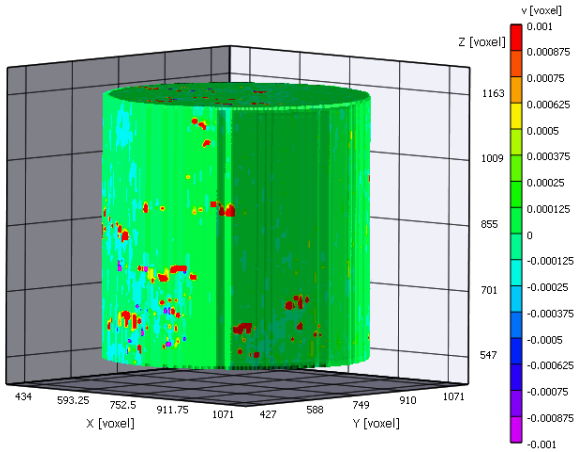
- Utilize part with aluminum spheres seeded in epoxy
- Operate x-ray machine at 100kV and 400µA (36W)
- Detector operated at 3.5 fps with 16 frame average
- Acquire 1099 projections
- No beam filter used
- Dimensions provide 3.5x magnification (36.4 effective voxel size)
- 94 minute scan

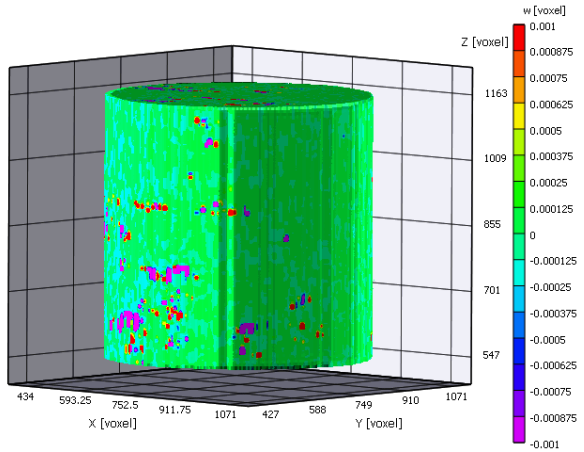
Single Scan Self-Correlation

- Determine subset size
- Determine step size
- General software familiarization

	u (voxel)	u (μm)	v (voxel)	v (μm)	w (voxel)	w (μm)
Mean	1.35E-04	4.93E-03	1.25E-04	4.55E-03	-9.69E-05	-3.53E-03
Standard Dev	1.62E-03	5.90E-02	1.61E-03	5.85E-02	2.47E-03	8.99E-02

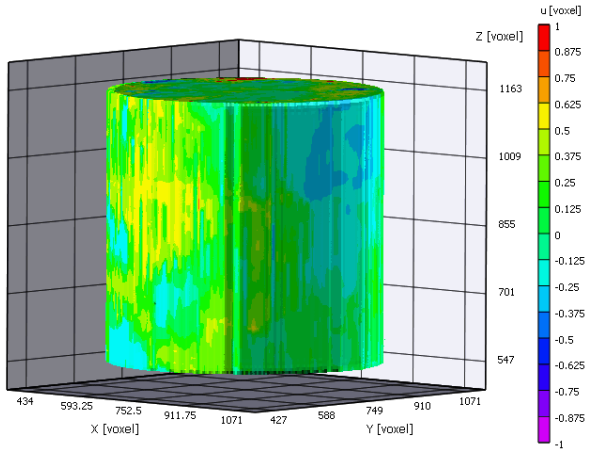


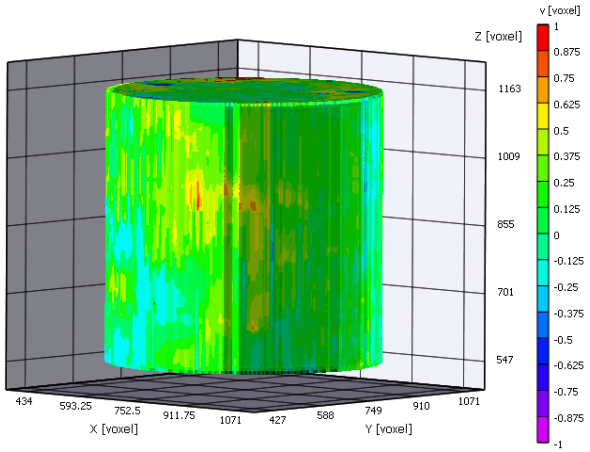


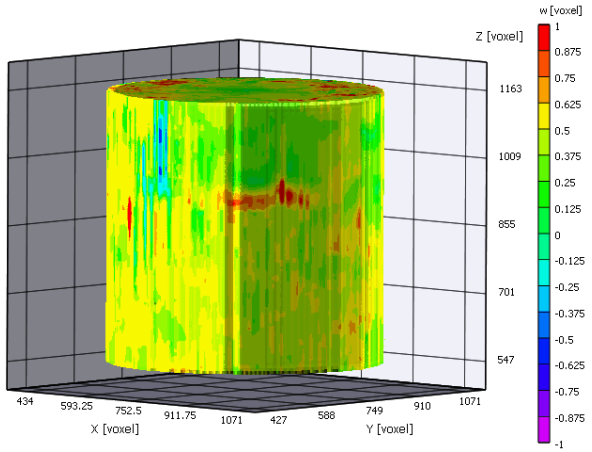


Multi-Scan Noise Floor

- Scan part multiple times, one right after another
  - 4 scans
- Each scan took 94 minutes (Overall continuous beam time 6+ hours)







Multi-Scan Noise Floor Data

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u-direction (movement in x)

	Scan 1&2	Scan 1&3	Scan 1&4	Scan 2&3	Scan 2&4	Scan 3&4
Mean (μm)	4.763	3.203	1.335	6.271	3.308	5.279
Standard Dev (μm)	10.762	12.59	15.73	12.22	10.88	12.91

v-direction (movement in y)

	Scan 1&2	Scan 1&3	Scan 1&4	Scan 2&3	Scan 2&4	Scan 3&4
Mean (μm)	5.006	3.079	3.052	7.343	6.761	8.082
Standard Dev (μm)	11.600	13.50	16.46	13.17	10.40	13.23

w-direction (movement in z)

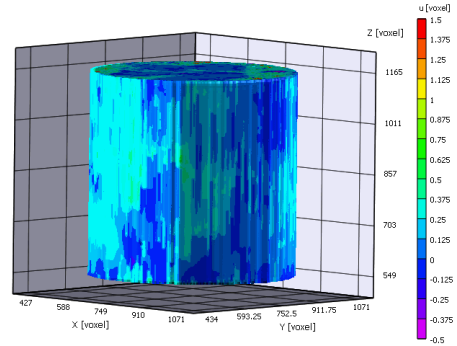
	Scan 1&2	Scan 1&3	Scan 1&4	Scan 2&3	Scan 2&4	Scan 3&4
Mean (μm)	16.28	22.38	25.39	9.728	12.51	6.797
Standard Dev (μm)	7.460	12.78	16.40	5.822	5.866	6.598

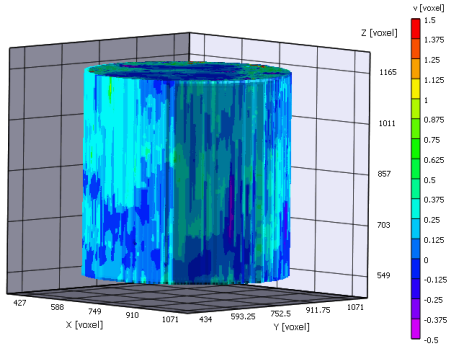
mean noise floor

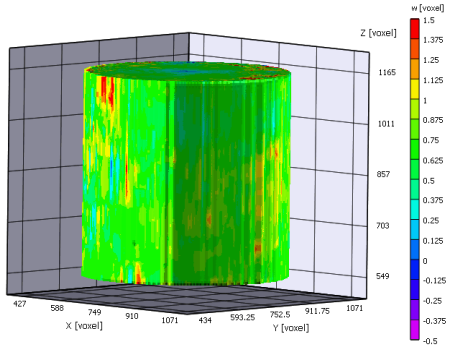
	u	v	w
Noise Floor (voxel)	0.344	0.354	0.252
Noise Floor (μm)	12.52	13.06	9.154

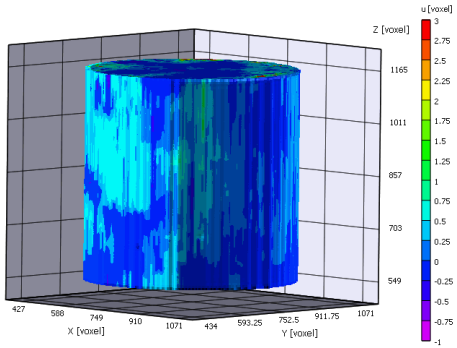
Rigid Body Translation

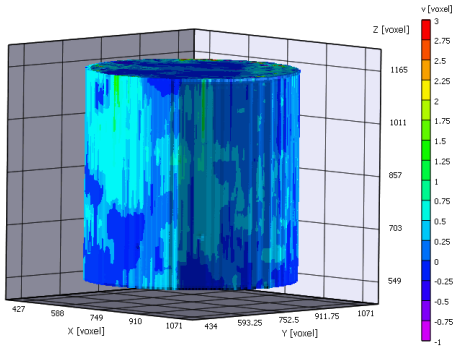
- Initial Scan
- Multiple Subvoxel Shifts
  - 10µm in z-direction
  - 6 total scan, 50µm total movement
- 10µm shift should match noise floor data

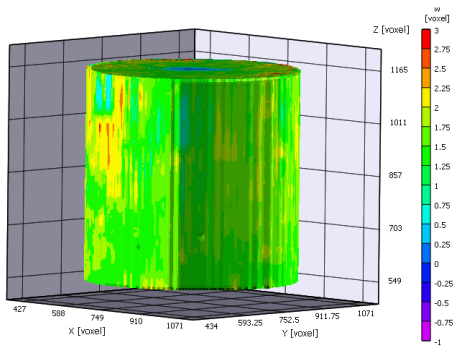












Rigid Body Translation Data

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	u	v	w
Mean (voxel)	0.166	0.151	0.451
Mean (μm)	6.037	5.493	16.41
Standard Deviation (voxel)	0.270	0.279	0.158
Standard Deviation (μm)	9.812	10.150	5.746

	u	v	w
Mean (voxel)	0.136	0.119	0.683
Mean (μm)	4.966	4.346	24.85
Standard Deviation (voxel)	0.231	0.244	0.235
Standard Deviation (μm)	8.415	8.897	8.541

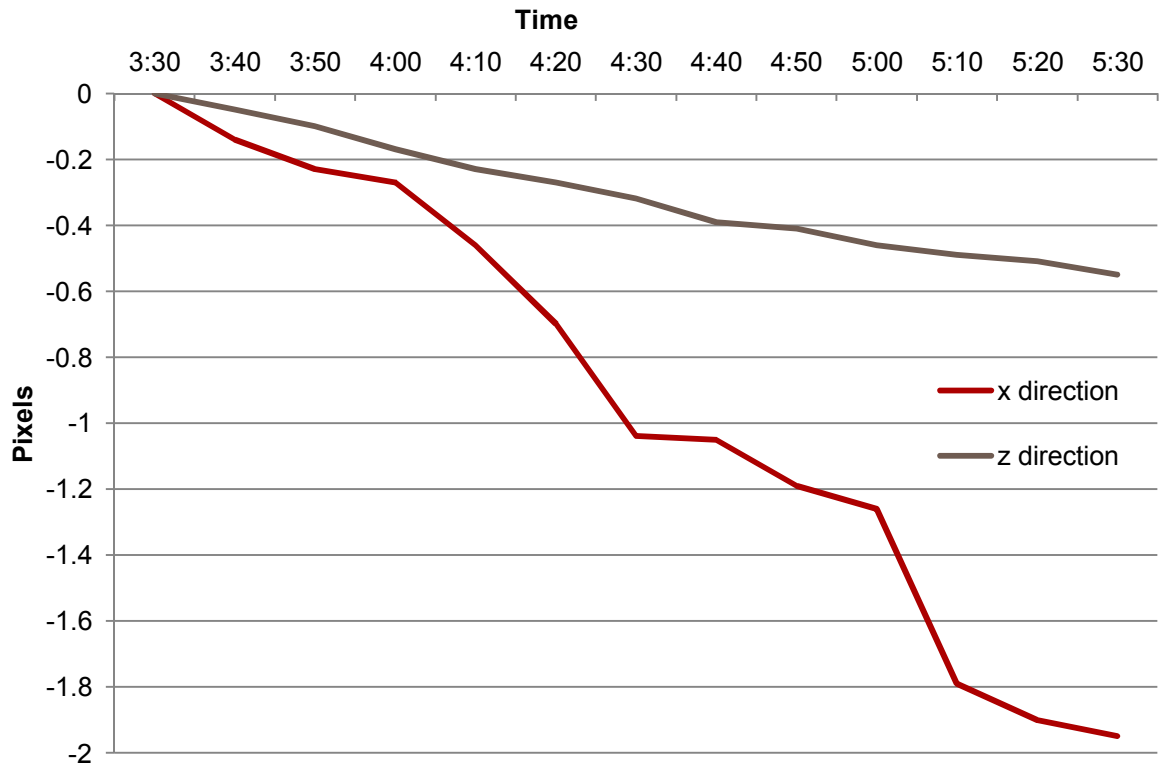
	u	v	w
Mean (voxel)	0.163	0.166	1.024
Mean (μm)	5.951	6.049	37.28
Standard Deviation (voxel)	0.343	0.371	0.329
Standard Deviation (μm)	12.473	13.487	11.994

	u	v	w
Mean (voxel)	0.164	0.164	1.037
Mean (μm)	5.974	5.981	37.75
Standard Deviation (voxel)	0.330	0.348	0.336
Standard Deviation (μm)	12.017	12.675	12.239

	u	v	w
Mean (voxel)	0.092	0.130	1.504
Mean (μm)	3.356	4.725	54.753
Standard Deviation (voxel)	0.350	0.335	0.348
Standard Deviation (μm)	12.737	12.191	12.682

X-ray Focal Spot Drift

- Acquire target image every 10 minutes over 2 hour period
- Shutter x-ray beam to prevent detector burn



Path Forward

Sandia National Laboratories

- Repeat translation experiment with high precision stage
- Conduct compression test
- Improve CT system calibration routines
- Continue search for material applications