LLNL D4DCT Datasets: Dynamic 4DCT Datasets using MPM-based Deformation

Hyojin Kim, Jingu Kang, Kyle Champley, Rushil Anirudh, Aditya Mohan

1. Introduction

Dynamic computed tomography (DCT) refers to reconstruction of moving or non-rigid objects over time while x-ray projections are acquired over a range of angles. The measured x-ray sinogram data represents a time-varying sequence of dynamic scenes, where a small angular range of the sinogram will correspond to a static or quasi-static scene, depending on the amount of motion or deformation as well as the system setup. The reconstruction of DCT is widely applicable to the study of object deformation and dynamics in a number of industrial and clinical applications (e.g., heart CT). In the material science and additive manufacturing applications, the DCT capabilities aid in the study of damage evolution due to dynamic thermal loads and mechanical stresses over time which provides crucial information about their overall performance and safety.

We provide two dynamic CT datasets (D4DCT-DFM, D4DCT-AFN) where the sinogram data represent a time-varying object deformation to demonstrate damage evolution due to several mechanical stresses (compression). The provided datasets enable training and evaluation of the data driven machine learning methods for DCT reconstruction. To build the datasets, we used Material Point Method (MPM)-based methods [2, 3] to simulate deformation of objects under mechanical loading, and then simulated CT sinogram data using Livermore Tomography Tools (LTT) [1].

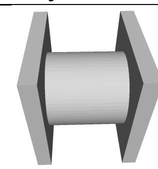
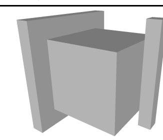
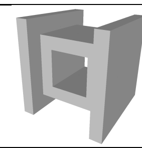
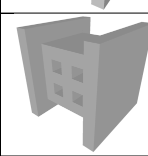
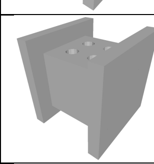
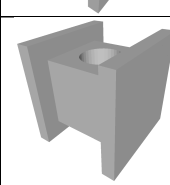
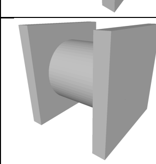
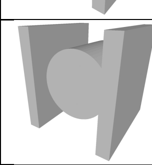
2. MPM Simulation

MPM is a hybrid Lagrangian/Eulerian approach and an application of Particle-In-Cell (PIC) methods for solving solid dynamic mechanics problems involving extremely large deformations and rotations. Among several MPM methods, second-order convected particle domain interpolation (CPDI2) MPM [2] was used to represent deformation of a type of aluminum under various loading conditions. Note that Kang implemented his own version of CPDI2 to perform the simulation. The material type used in the simulation is 6061 aluminum alloy and the properties adopted to represent the material behavior are as follows: density 2.70 g/cm, Young's modulus 68.9 GPa, Poisson's ratio 0.33, yield strength 276.0 MPa. The perfect plastic hardening is assumed in the simulation results:

We generated 157 data samples of simulated deformation. The deformation sequence of each data sample consists of 360 or 720 frames, each of which is saved as a wavefront obj format with an additional text file storing particle densities. The data sample name is formatted as follows: S[s]-[m] where s: shape type, m: mechanical loading type

Figure 1 and Figure 2 summarize the dataset based on two criterions: the shape type, mechanical loading scenarios, respectively. Based on the criterions, we split the entire samples into training and validation (evaluation) sets. In the first criterion based on the shape type, 03 and 04 types are used for validation while the remaining types are used for training. The second criterion is based on the mechanical loading, and the samples with 2 mechanical loading points are used for training while the ones with 4 mechanical loading points (700) are used for validation.

Figure 1: Shape Type

Shape Type	Geometry	# Deformations	Obj
00	Cylinder or Cube	10	
01	Rectangular bar	15	
02	Rectangular tube	17	
03	Rectangle (rectangular voids)	17	
04	Rectangle (circular voids)	17	
05	Rectangular/circular tube	19	
06	Cylinder	16	
07	Cylinder	17	

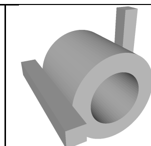
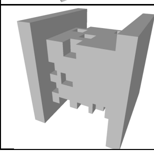
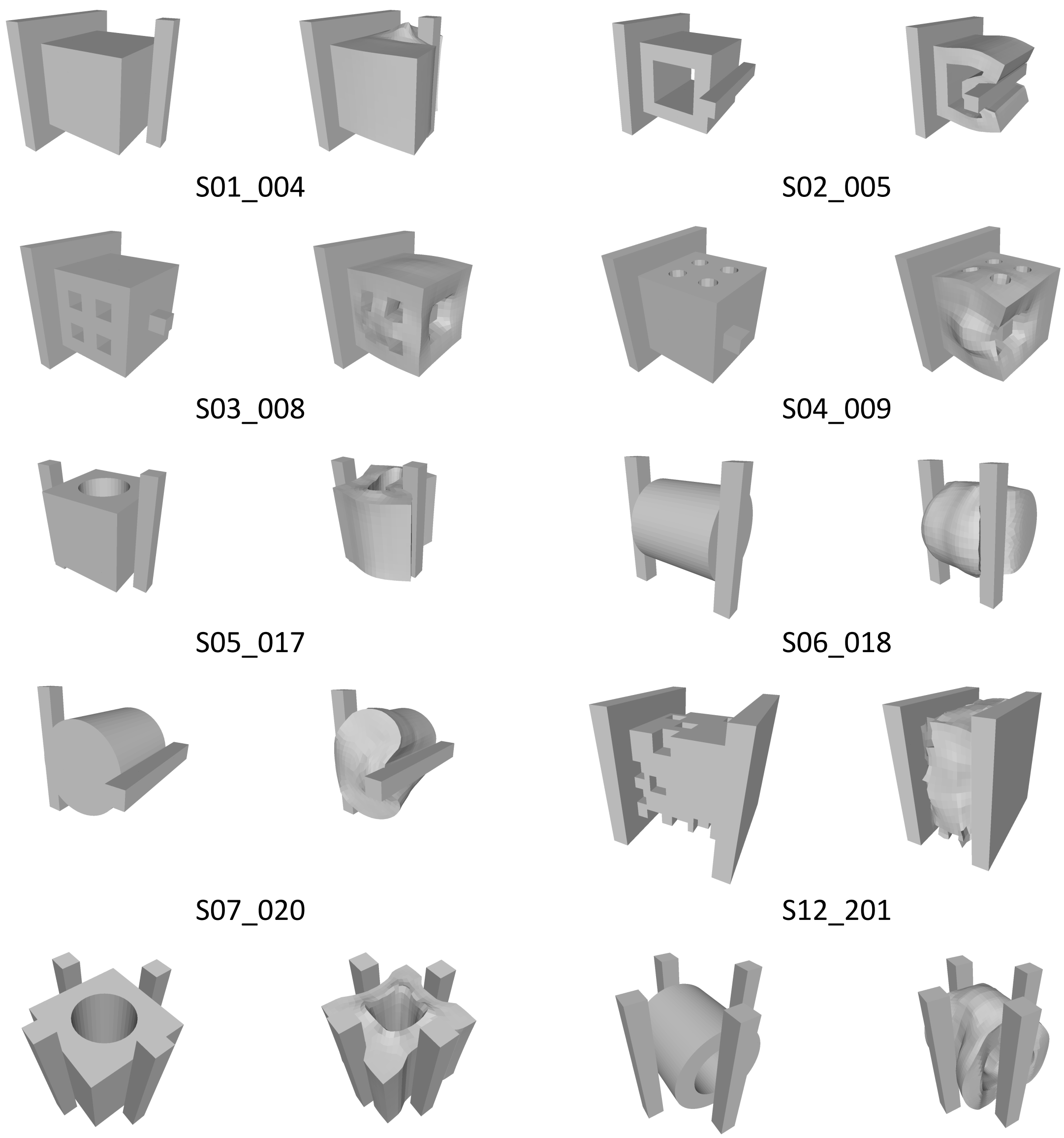
08	Cylinder (empty hull)	17	
12	Rectangle (random voids)	12	

Figure 2: Deformation under different mechanical loading scenarios. The first and last frames only are shown here.

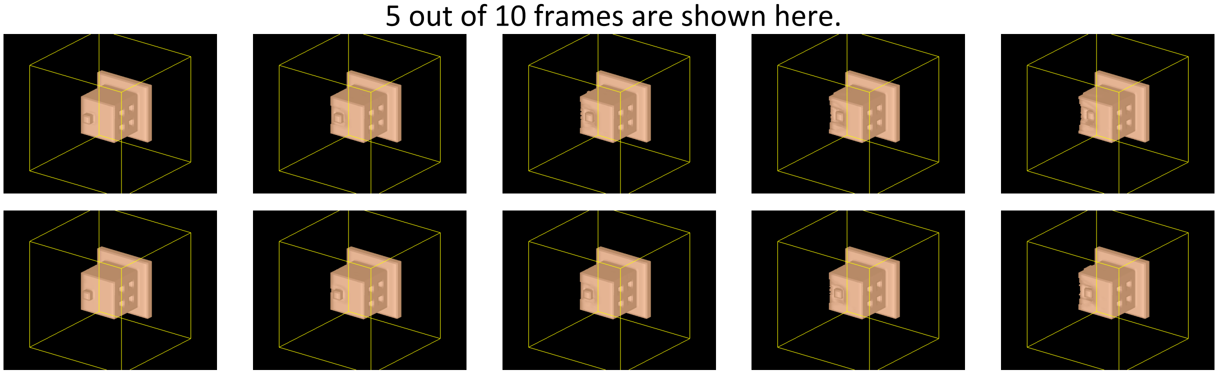


3. D4DCT-DFM

Given the MPM-based deformation dataset described above, we generated two CT datasets: D4DCT-DFM, D4DCT-AFN. The CT dataset refers to a set of data samples, each of which contains ground truth volume sequence with its simulated *dynamic* sinogram data using LTT [1]. In this section, we describe D4DCT-DFM representing dynamic 4DCT of material deformation. Given each MPM data sample of object deformation sequence, we generated 5 data samples of volume sequence with the sinogram data for data augmentation. The first data sample was generated from equally spaced frames whereas the rest 4 data samples were generated from randomly spaced deformation frames, as shown in Figure 3. The total number of data samples is 785. The number of projections used in the sinogram data is 90, the angular range is 180 and 720, and the detector row size is 80. The volume dimension is 80^3, and the number of frames is 10.

For the *dynamic* sinogram simulation, we used 90 frames (either uniformly or randomly sampled as described previously) from the original MPM deformation sequence. The original 90 frames (in obj format) were voxelized into 90 80^3 volume frames (in 3D raw format). For each volume frame, we performed forward projection using LTT to generate its sinogram, which becomes 90 sinogram frames in total. Then we combined all sinogram frames into a single *dynamic* sinogram data in which *n*th row was extracted from *n*th row of *n*th sinogram frame (n=[1,90]). 10 frames out of 90 volume frames are provided as ground truth volume sequence.

Figure 3: Two sample volume sequences in D4DCT-DFM given a single MPM deformation data. 5 out of 10 frames are shown here.



4. D4DCT-AFN

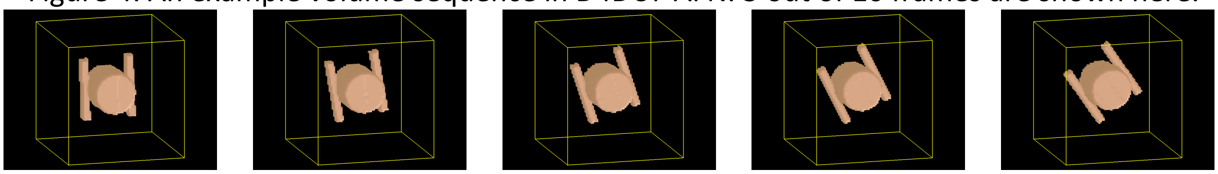
Given each MPM data sample of object deformation sequence, we generated 5 different data samples of affine transformation sequence and its sinogram data, which become 785 samples in total. We randomly sampled a frame out of the entire deformation sequence, and then applied randomly generated affine transformation to the frame to generate affine sequence data. The sinogram dimension is the same as the one in D4DCT-DFM.

In addition to the sinogram and the ground truth data of 10 frames provided in the D4DCT-DFM, this data includes affine transformation parameters of all 10 frames in a single text file. An example affine transformation file is like this:

0 r 1 -2.268792 t 0.008978 0.009661 0.004654
1 r 1 -6.875544 t 0.024689 0.026478 0.014463
…

Elements of each row are frame index (0-9), r (rotation), rotation axis (0, 1 or 2), rotation angle in degree, t (translation), tx, ty, tz in pixel, respectively. All rotation and translation are based on the first frame's center position.

Figure 4: An example volume sequence in D4DCT-AFN. 5 out of 10 frames are shown here.



Disclaimer

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-MI-816695

References

[1] K. Champley, Livermore Tomography Tools (LTT) Software Package, 2016

[2] A. Sadeghirad, R.M. Brannon, J.E. Guilkey, Second-order convected particle domain interpolation (CPDI2) with enrichment for weak discontinuities at material interfaces, 2013, Int. J. Numer. Meth. Engng, 95: 928-952.
[3] Sadeghirad, A. & Brannon, Rebecca & Burghardt, Jeff, Convected particle domain interpolation technique to extend applicability of the material point method for problems involving massive deformations, 2011, International Journal for Numerical Methods in Engineering. 86: 1435-1456.
[4] ASM Handbook, Volume 2: Properties and Selection: Nonferrous Alloys and Special-Purpose Materials ASM Handbook Committee, p 102, DOI: 10.1361/asmhba0001060