Simulated DIC Images for Design and Validation of Cryogenic Mechanical Testing

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Abstract. Super-conducting magnets and their supporting structures in tokamak fusion power plants are subjected to cryogenic temperatures, electromagnetic loads and neutron irradiation. Experimental validation data will be needed for the simulations required to qualify these components. Mechanical testing using Digital Image Correlation (DIC) is challenging at cryogenic conditions due to the use of vacuum vessels with constrained optical access. Given the cost of accessing cryogenic test facilities, we have developed a python tool to simulate DIC in constrained optical environments using the open-source graphics software Blender. We plan to apply our tool to analyse uncertainties for an experiment using a cryogenic magnetic probe requiring stereo DIC to be performed down a long narrow pipe. Results and uncertainties from the Blender-Python tool will be compared to experimental results from our mock-up at the conference.

Possible Sessions

12. Model Validation, 15. Nuclear Applications: Fission & Fusion, 16. Optical and DIC Techniques

Introduction

Super-conducting magnets are at the core of the plasma containment system in a fusion power plant. Throughout operation, the super-conducting magnets and their supporting structures will need to withstand cryogenic temperatures, electromagnetic loads, and neutron irradiation. Experimental validation data under cryogenic conditions is needed for the extensive simulations required to design and qualify these magnets and structures. However, it is challenging to undertake mechanical testing at cryogenic conditions due to the environmental conditions inside the test rigs, and the optical constraints associated with imaging into insulated vacuum vessels. As a non-contact full-field technique, DIC has the potential to provide the required simulation validation data. Due to the volumetric deformation of samples within cryogenic environments, it would be ideal to use a stereo DIC setup but this poses its own challenges due to the common limitation on space. DIC at cryogenic conditions is still not well-developed, and only a limited number of studies have used DIC for mechanical testing in cryogenic environments. Pelegrin et al. [1] captured thermo-mechanical data from a high temperature superconducting (HTS) magnet coil using DIC. Zhang et al. [2] performed 2D DIC on a cryo-mechanical rig for materials testing at liquid helium temperatures. Alharake et al. [3] utilised DIC to measure deformation of HTS pancakes. Since cryogenic experiments are challenging and expensive, it is optimal to be able to simulate the experiments before undertaking them to predict uncertainties and address challenges with the tests. DIC simulation tools like this have been developed before. P. Lava et al. have developed an image deformation module within MatchID to more accurately compare finite element data to experimental data [4]. D. P. Rohe and E. M. C. Jones have utilised Blender to generate synthetic DIC images [5]. However, MatchID has commercial license restrictions and Blender itself is not packaged in a way that would allow DIC simulation parametric sweeps to be run on a supercomputing cluster without considerable user development. Therefore, we have developed an open-source python module specifically for simulating DIC that uses Blender for rendering. This tool can then be run on a cluster to perform parallel sweeps of experimental parameters. This tool is freely available to the research community as part of the pyvale python package.

Computational Method

We used the Blender python application programming interface (API) to build our DIC simulation tool. This can run Blender headless (without a GUI) through python using the bpy module. The tool is a python interface on top of Blender's API, which specifically exposes functionality for rendering DIC images. This gives a simpler and more understandable user interface for utilising Blender in this way as well as allowing specific functionality for DIC such as applying speckle patterns, deforming meshes and rendering calibration targets.

The basic workflow of our Blender-Python tool is shown in Figure 1. The user only needs to provide three main inputs: simulation results (including an object mesh), camera parameters, and light parameters. The most important class within this tool is the BlenderScene class. This class is used to initialise a scene, a container for all objects such as cameras, parts and lights. The user can then add a part to the scene, from the input mesh. They can then add a single camera for 2D DIC, or multiple for stereo DIC. Convenience functions also exist to add a face-on or symmetric stereo DIC setup, given camera parameters and a stereo angle. Calibration functionality is also included: either a calibration file can be output, or a set of calibration images can be rendered. A light can then be added to the scene. A speckle pattern can then be added to the sample, either by providing a speckle image file, or a speckle pattern is generated based on user defined parameters. At this point, the Blender file can also be saved and/or images rendered; or deformation can be applied to the mesh (using the simulation results) and images rendered at each timestep. This setting of deformation is mesh dependent, so systematic errors will be seen unless the mesh is sufficiently fine. The rendered images can then be run through a DIC engine. This tool is part of a larger sensor simulation package named pyvale which is open-source and available on GitHub: https://github.com/Computer-Aided-Validation-Laboratory/pyvale.

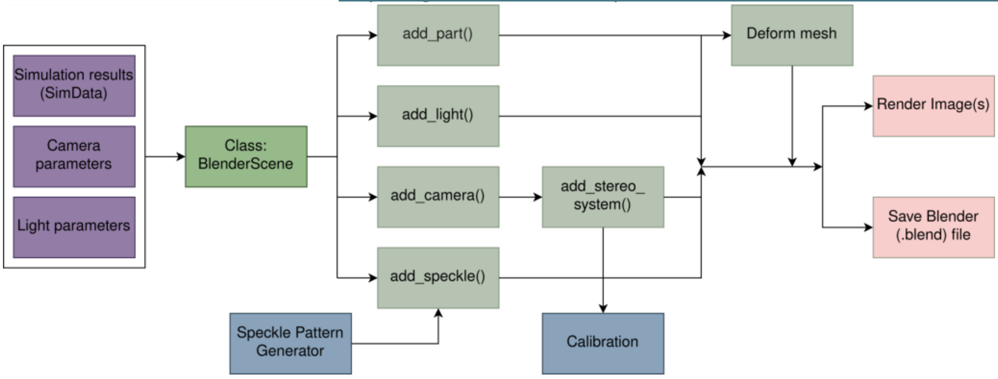

Figure 1: Flowchart showing the workflow of the Blender-Python tool

Demonstration of Blender-Python Tool for Cryogenic Magnetic Probe Case

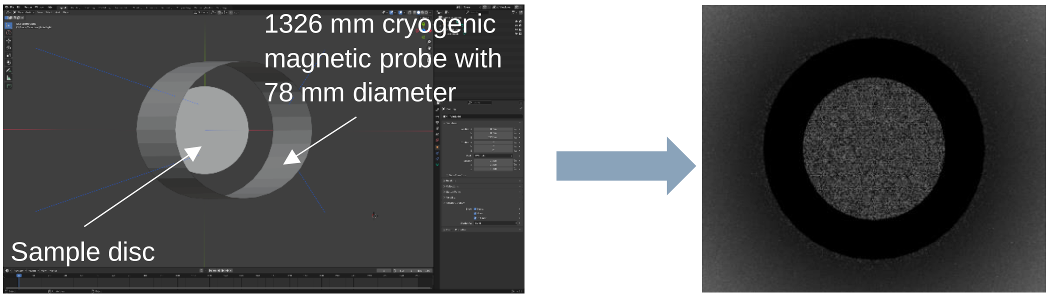

Figure 2: The Blender scene of the setup (left) and the rendered image of the speckled sample (right)

To quantify the accuracy of this method of rendering DIC images, firstly 2D DIC images were benchmarked against images produced via a 2D image deformation code in pyvale based on [6]. This comparison meant that any error between the two sets of images were due to the imaging method alone, not the DIC processing. Both rigid body motion and deformation cases were compared. For all cases, the error between the two data sets was on the order of 0.002 pixels. We then applied our tool to analyse the case of a stereo setup imaging down a wide-bore cryogenic magnet with a 78 mm diameter and 1326 mm length as shown above in Figure 2. This case has many challenges including lighting, depth of field and lack of space for a stereo setup. Utilising this tool will aid in not only designing the experimental setup, but also to predict uncertainties for the experiment.

Conclusion and Future Work

In this work, we developed an open-source python-based tool for simulating DIC images. This can be used to test different experimental setups, as well as quantify uncertainties for a future experiment. This is especially vital for experiments with challenging optical setups or that are expensive to run. To validate this tool, a mock-up of a wide bore cryogenic magnet system is being built. In addition to the work outlined above, we will also present experimental work from this mock-up, and will compare it to the results from the Blender-Python tool.

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