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14. ABSTRACT

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RPPR Final Report
as of 16-Jan-2020

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Major Goals: The objective of this DURIP was to develop an experimental facility for the full-field, optical characterization of the dynamic response of architected materials and structures across the scales. Two main experimental techniques were proposed using i) high-speed photography and ii) advanced motion capture to resolve the multi-scale high-resolution characterization of events such as wave propagation and dynamic large deformations in novel metastructures. The development of the experimental facility was successfully completed in mid-May 2019 and is currently being used for the aforementioned objectives with an initial focus of investigating the impact performance of tensegrity lattices.

Accomplishments: The development of proposed experimental facility was successfully completed in mid-May 2019 and is currently being used for the aforementioned objectives with an initial focus of investigating the impact performance of tensegrity lattices. Using the facility we have demonstrated begun analyzing tensegrity lattices using high-speed imaging and VICON motion tracking. Preliminary results demonstrate our ability to capture large deformations (order one meter) with sub-mm scale at a thousand fps. We are in the process of developing necessary software to transform the experimentally gathered data into suitable measures of deformation for comparison to theoretical and numerical models.

Training Opportunities: During the period of performance the PIs and their students were trained on the use of Photron high-speed imaging cameras and VICON motion capture.

Results Dissemination: Nothing to Report

RPPR Final Report
as of 16-Jan-2020

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

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Participant: Claudio V Di Leo

Person Months Worked: 12.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: Julian J Rimoli

Person Months Worked: 12.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Co PD/PI

Participant: Massimo Ruzzene

Person Months Worked: 12.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

DURIP: Optical characterization of the dynamic mechanical response of advanced aerospace materials and structures

Final Report Covering
6/15/2018 — 6/14/2019

Objectives

The objective of this DURIP was to develop an experimental facility for the full-field, optical characterization of the dynamic response of architected materials and structures across the scales. Two main experimental techniques were proposed using i) high-speed photography and ii) advanced motion capture to resolve the multi-scale high-resolution characterization of events such as wave propagation and dynamic large deformations in novel metastructures. The development of the experimental facility was successfully completed in mid-May 2019 and is currently being used for the aforementioned objectives with an initial focus of investigating the impact performance of tensegrity lattices.

Experimental Facility

The main experimental facility is shown in Fig. 2 and is composed of a high bay drop testing facility. The facility measures approximately 15ft deep by 20ft wide and 25ft high, allowing for the drop testing of structures of significant size at high impact energies.

The facility is instrumented with 12 Vicon Vantage V5 cameras, 10 of which are shown in Fig. 2. The remaining two cameras stand on a tripod facing in the same direction as the photograph shown in Fig. 2. The facility is also equipped with two Photron Mini AX200 cameras capable of frame rates ranging from 6,400fps at 1Megapixel to 900,000fps. The high speed imaging cameras are shown in Fig. 1. Each set is composed of a camera, LED lighting and an individual laptop computer for data recording. A such each camera may be individually deployed across the facility with ease. In conjunction, the Vicon motion capture system and Photron high-speed imaging cameras may be used to capture large and small scale deformations.

The experimental facility was completed in mid-may and only preliminary experiments to validate the capabilities of the equipment have been performed thus far. We describe next preliminary experiments capturing the impact deformations of a tensegrity lattice using high-speed imaging and Vicon motion tracking.



Figure 1: Photron High-Speed Imaging Camera

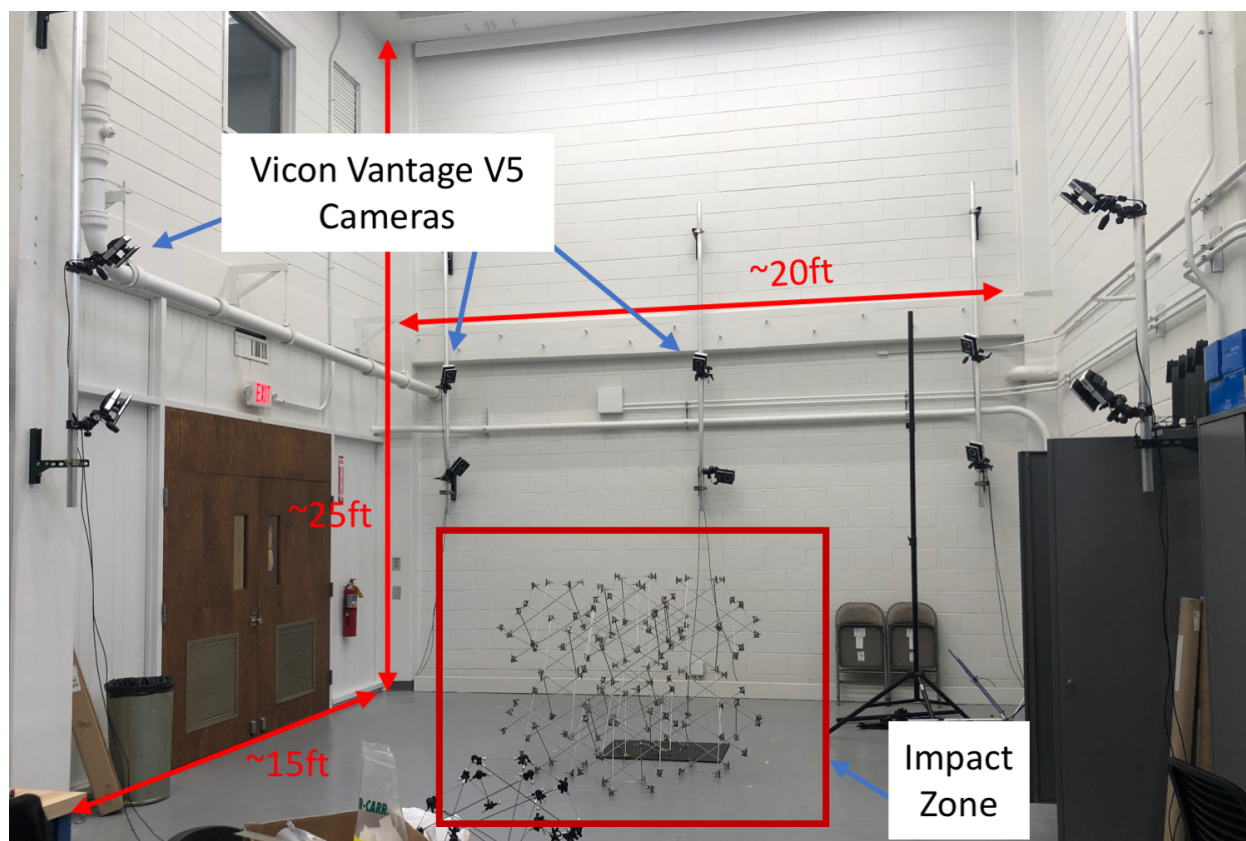


Figure 2: Experimental structural dynamics optical characterization facility

High-Speed Imaging of Tensegrity Lattices

Experimental tests were performed using a truncated octahedron tensegrity structure as shown in Fig. 3. A tensegrity lattice is a structure composed of compression bars — carbon fiber reinforced polymer (CFRP) bars shown in Fig. 3 — connected through tensile elements — steel cables in Fig. 3. Tensegrity structures have been predicted to possess unique properties in their ability to accommodate impacts through the buckling of individual elements without collapse of the structure through localization of the deformation (Rimoli and Pal, 2017; Rimoli, 2016). Although modeling of these structures has been demonstrated in the literature, detailed experimental investigation of these structures is in its infancy and thus of critical importance.

Impact tests were performed on the tensegrity structure shown in Fig. 3 from a height of 5ft and recorded at 500fps with a shutter speed of 1/1000s. Two configurations of the structure were used with different diameter CFRP compression bars. Fig. 4 shows impact tests using *thin* bars which undergo significant buckling. Fig. 4(c) shows the maximum deformation during impact which is

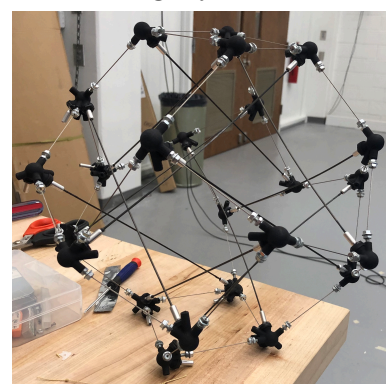


Figure 3: Truncated octahedron tensegrity structure

accommodated entirely through buckling and is recoverable. A measure of the energy stored in this deformation can be seen from the maximum height of the bounce back which is shown in (d). Similar results are shown in Fig. 5 for a configuration with thick CFRP compression bars. As shown during maximum deformation in Fig. 5(d), the structure in this configuration does not undergo as significant a deformation as in the thinner bar configuration. Further, we can see from the bounce back in Fig. 5(d) that a smaller amount of elastic energy was stored and recovered through buckling.

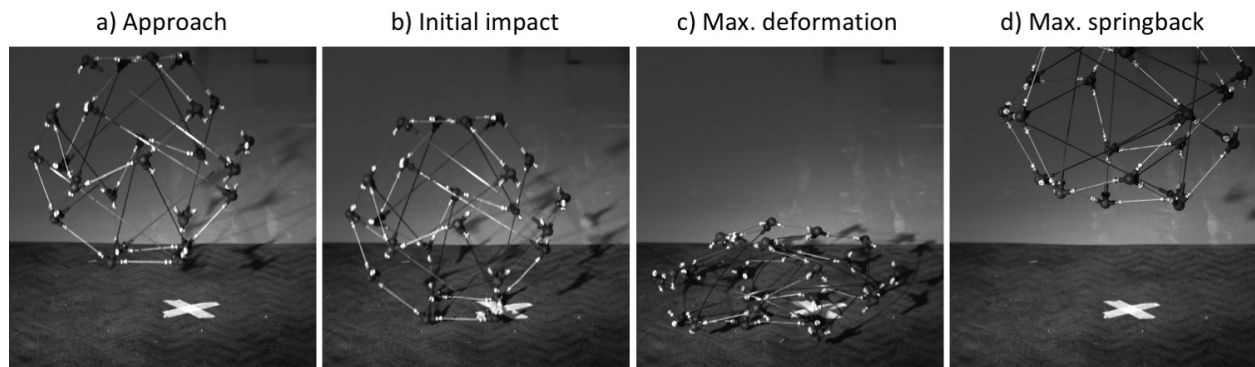


Figure 4: Impact of a tensegrity structure with thin (1/16 in diameter) CFRP compression bars.

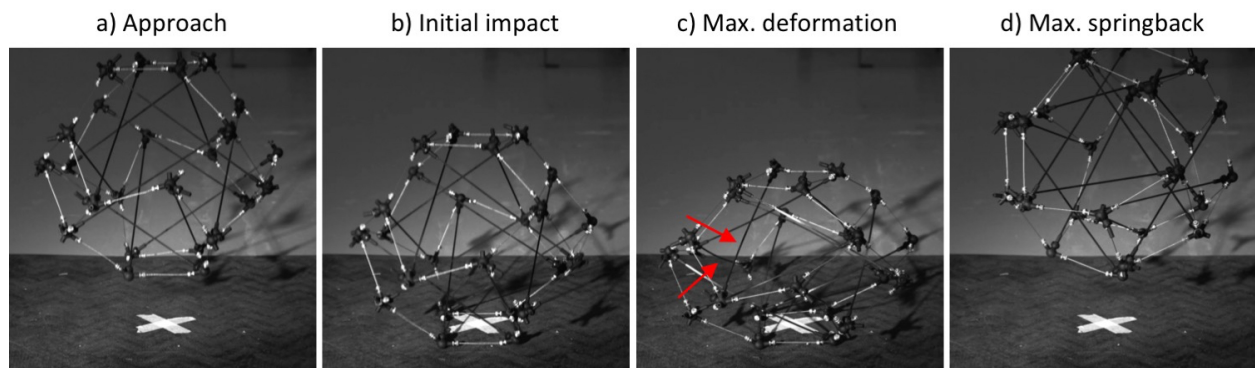


Figure 5: Impact of a tensegrity structure with thick (3/32 in diameter) CFRP compression bars.

As demonstrated theoretically in (Rimoli and Pal, 2017), the truncated octahedral tensegrity structure may be tiled to build a larger lattice with unique mechanical properties. As part of this ongoing research such a lattice has been manufactured and is also being tested for its impact properties. Fig. 6 shows a lattice constructed of four unit cells (i.e. having a 2 x 1 configuration) being impacted both in its horizontal configuration, images (a) and (b), and on its vertical configuration (c) and (d). Beyond their ability to undergo large recoverable deformations, an important feature of this lattice is that deformation does not localize to a single unit-cell or row of unit-cells as can traditionally occur in truss-like structures. As shown in Fig. 6(d), As the structure impacts, deformation and buckling occurs throughout the structures and is not localized at any individual unit cell.

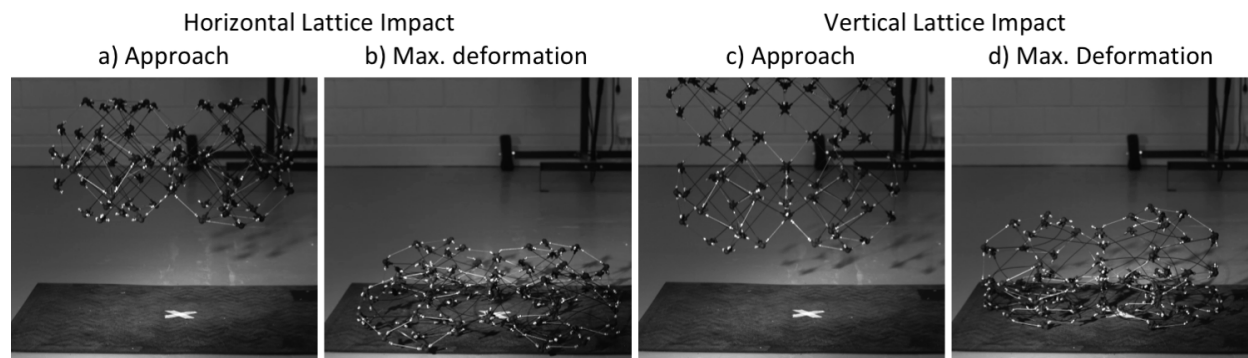


Figure 6: Impact of a tensegrity lattice composed of four truncated octahedral unit cells.

VICON Motion Tracking of Tensegrity Lattices

A second critical component of this research was the use of motion tracking to capture large dynamic structural deformations. Preliminary experiments were performed using the same lattice as truncated octahedron lattice. Tracking of the nodes was achieved by careful coating of the nodes with reflective materials suitable for VICON motion tracking, see Fig. 7 (a). The process of creating good reflective surfaces for motion tracking is complex and significant effort has been put in this subject.

The motion tracking software provides the position of all reflective nodes in space as shown in Fig. 7(b) which may also be visualized including the compressive bars connecting various nodes as shown in Fig. 7(c). Motion tracking allows point-wise tracking of all the nodes with sub-mm precision at frame rates approaching 1000fps. The software uniquely identifies each node and can distinguish the motion of individual nodes. Fig. 8 shows an example of tracking the position of two unique nodes in the lattice in time. Here the lattice was simply picked up from the floor and dropped for a small impact. The motion of the two node selected is well characterized and captured. Similarly, Fig. 9 shows snapshots of a tensegrity structure being deformed in such an impact the associated motion tracking of all the nodes.

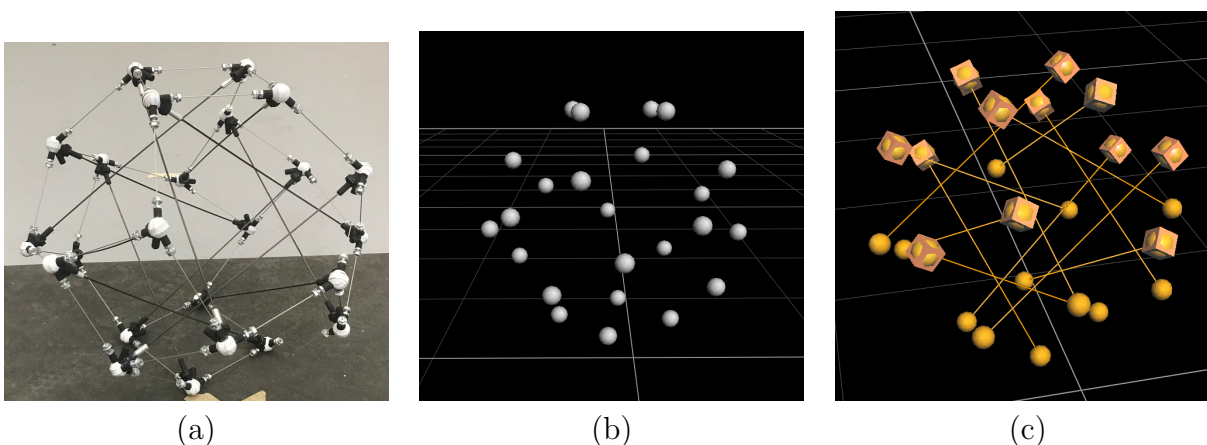


Figure 7: a) Truncated octahedron tensegrity lattice with reflective nodes. b) Vicon Motion tracking image of the tensegrity structure, and c) Motion tracking with node connectivities.

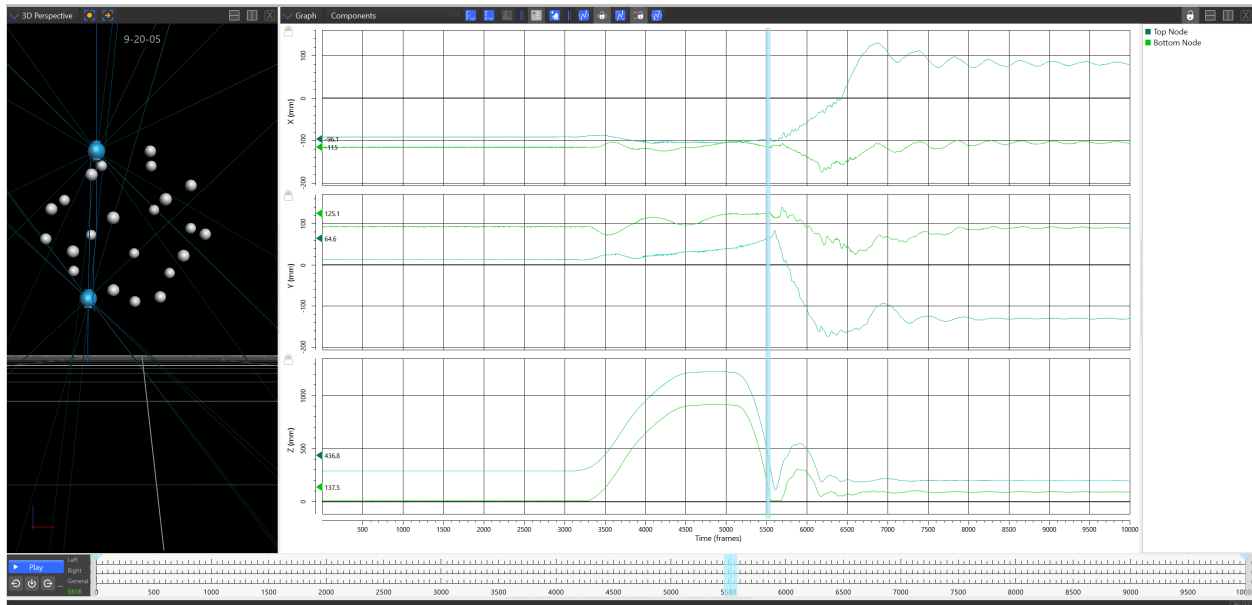


Figure 8: Vicon software showing unique spatial location tracking of two individual nodes in the tensegrity lattice. The experimental data is representative of picking up the lattice from the ground and dropping for an impact.

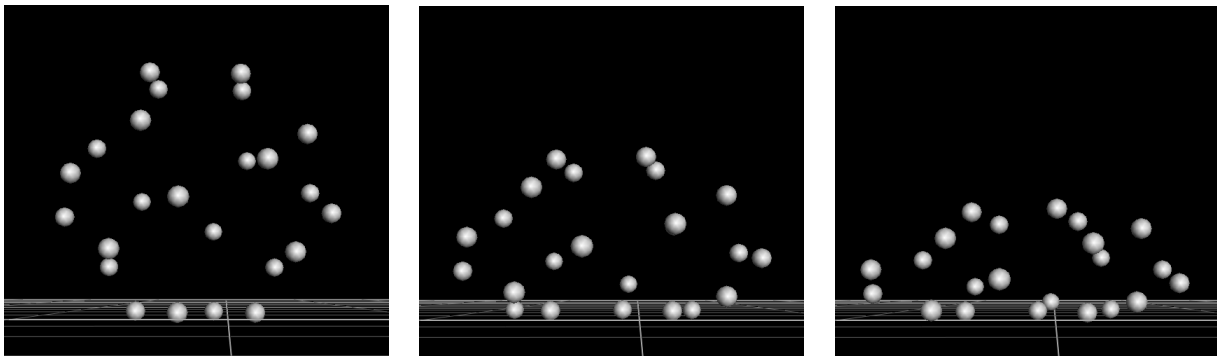


Figure 9: Vicon motion tracking of tensegrity nodes during an impact experiment.

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- Rimoli, J.J. On the impact tolerance of tensegrity-based planetary landers. *In 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference* (p. 1511), 2016.