MULTIDIC AND DUODIC: OPEN-SOURCE SOFTWARE FOR 3D DIGITAL IMAGE CORRELATION AND THEIR APPLICATIONS IN BIOMECHANICS

Dana Solav (1)

1. Technion – Israel Institute of Technology, Israel

Introduction

Three-dimensional Digital Image Correlation (3D-DIC) is an optical-numerical technique for measuring the 3D shape and full-field displacement, deformation, and strain, from stereo images of the surface of an object, using digital images captured from multiple views. 3D-DIC is increasingly used in recent years for various biomechanical applications [1], e.g., for characterizing the mechanical behavior of hard and soft tissues, biomaterials, and biomedical devices. 3D-DIC is particularly valuable for identifying material parameters and validating the predictions of numerical simulations. However, the high cost of commercial 3D-DIC software that are typically also proprietary and closed-source, may pose a barrier and hinder the many qualities of 3D-DIC, especially for students and researchers. Recently, a few free open-source 3D-DIC software have been published (e.g., [2,3,4]). Specifically, MultiDIC [3] (github.com/MultiDIC) focuses on multi-view applications and enables the instantaneous calibration of numerous cameras using a dedicated 3D calibration object. DuoDIC [4] (github.com/SolavLab/DuoDIC), on the other hand, works only with two cameras, but offers a simpler calibration procedure that requires only a flat calibration target. Both toolboxes are written in MATLAB, providing the flexibility and simple implementation that meet the needs of the experimental biomechanics community.

Methods

The 3D-DIC procedure in MultiDIC and DuoDIC is organized in four main steps [3, 4]:

1. stereo camera calibration: computing extrinsic and intrinsic parameters from a set of calibration images.
2. 2D-DIC (image correlation): analyzing speckled specimen images to identify grids of matching points using spatial and temporal cross-correlation.
3. 3D reconstruction: the results of step 1 and step 2 are combined to reconstruct image points in 3D space.
4. post-processing: the 3D point locations from step 3 are used to derive the full-field displacement, deformation, and strain maps.

We conducted several experiments for validating the displacement and strain results, and for demonstrating their efficacy in various biomechanical studies. Rigid translation and rotation experiments were used to evaluate the accuracy of displacement results and the strain errors (as any deviation from zero strain is considered a measurement error). Additionally, the ability of the 360-deg MultiDIC setup to reconstruct 3D surfaces from more than two cameras was examined by computing the merging errors between overlapping surfaces reconstructed by adjacent camera pairs.

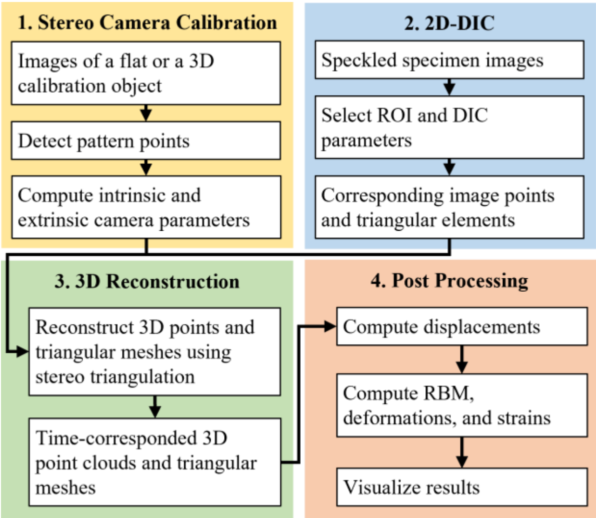

Figure 1: the 3D-DIC algorithm workflow implemented in MultiDIC and DuoDIC.

Results

Using DuoDIC, with two cameras in a stereo setup, rigid body translations (15 increments of 0.2 mm) were accurate to within $(1.3\pm1.1)\cdot10^{-3}$ mm (mean±STD) and the strain errors were $(3.4\pm2.3)\cdot10^{-4}$. Using MultiDIC, with 12 cameras in a circular array, a full 360-deg 114 mm diameter cylinder was reconstructed with merging errors of 0.06±0.03 mm.

Discussions

We demonstrate the efficacy of open-source 3D-DIC software, such as MultiDIC and DuoDIC, in various biomechanical investigations. The software were successfully used in various biomechanical applications, such as imaging below-knee amputees' residual limbs [5] for informing patient-specific prosthetic socket design [6], measuring human facial deformation for designing conformable wearable sensors [7], and for identifying unique sets of hyperelastic soft-tissue material parameters from indentation test results [8].

References

1. Palanca et al, Int Biomech, 3.1:1-21, 2016.
2. Turner, Sandia Report, 2015.
3. Solav et al, IEEE Access, *6*:30520-30535, 2018.
4. Solav et al, J Open Source Softw, 7.74:4279, 2022.
5. Solav et al, IEEE Tran Biom Eng, 66.10:1740-2752, 2019.
6. Herr H et al, US20210145608A1 patent, 2019.
7. Sun et al, Nat Biomed Eng, 4.10:954-972, 2020.
8. Oddes et al, Eng Arch, doi.org/10.31224/2697, 2022.