FE-based Heterogeneous Digital Volume Correlation to Measure Large Deformations of Breast's Soft Tissues

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Abstract. Breast cancer surgery stance differs from the preliminary imaging position of the patient. Being able to reposition a tumour from prone to supine position is key to bypass current invasive techniques. This study aims to prove the feasibility of using FE-Based regularised Digital Volume Correlation (DVC) to map the deformation of a breast between two positions submitted to gravity. Based on a segmented mesh and a 3-step DVC procedure, the large amplitude displacement field of the hard-soft tissue was successfully recovered.

Introduction

One woman over eight is likely to be diagnosed with breast cancer. For breast conservative surgery, surgeons mentally assess the relocation of the tumour due to the change of stance [1]. Numerical simulations provide a good alternative to estimate the new location of the tumour in a different stance. However, numerical models rely on experimental data for validation purposes. Therefore, the measurement of a full displacement field of *in vivo* soft tissues is crucial. This study provides a proof of concept of the use of Digital Volume Correlation to evaluate the hard/soft tissue deformations of a female quarter of thorax between two scans [2].

Material and Methods

A left quarter of a thorax (of size 0.27 × 0.26 × 0.06 m) was extracted from a female corpse. Fifteen biomarkers were placed on the surface and inside the breast to provide partial displacement information. The sample was imaged via micro-computed tomography with a resolution of 0.34 mm with angles of -45° and -60° with respect to the axial plane. The images were first segmented to label the soft tissue, the ribs and the bones using 3D Slicer software. A segmented image was created for both initial (-60°) and final (-45°) configurations. Then an extra (skin) layer of 15 voxels was added around the geometry to help DVC register the external surfaces. The segments were smoothed and a multi-part mesh was generated using ScanIP Simpleware software (courtesy of Synopsys) and avoiding sub-voxel elements. To measure large deformations of the soft tissue, a 3-step DVC pipeline was followed. First, a preliminary solution was computed based on the markers placed on the skin. Then, heterogeneous regularised DVC [3] was run on the segmented images to provide a better estimation of the surface displacement of each segment (elastic contrast between the soft tissue and the bones was 10^6, and cartilage was 10^4). DVC was finally run with a regularization length of 4 voxels to compute the full displacement field on the original volumes. Last, an *a posteriori* uncertainty quantification was introduced to evaluate the reliability of the solution.

Results

The large amplitude displacement field and resulting Green-Lagrange strains (up to 25% in magnitude) as well as the inframammary fold were successfully recovered by the method (Fig. 1). The final RMS residual was equal to 18.3 gray levels and the *a posteriori* standard strain uncertainty was less than 5×10^{-3}. A further validation was provided by computing the Root Mean Squared Error (RMSE) between the deformed surfaces and the segmented ones. The measured error was a few millimeters (between 2.2 to 3.1 mm, which corresponds to a range of 7 to 9 vx).

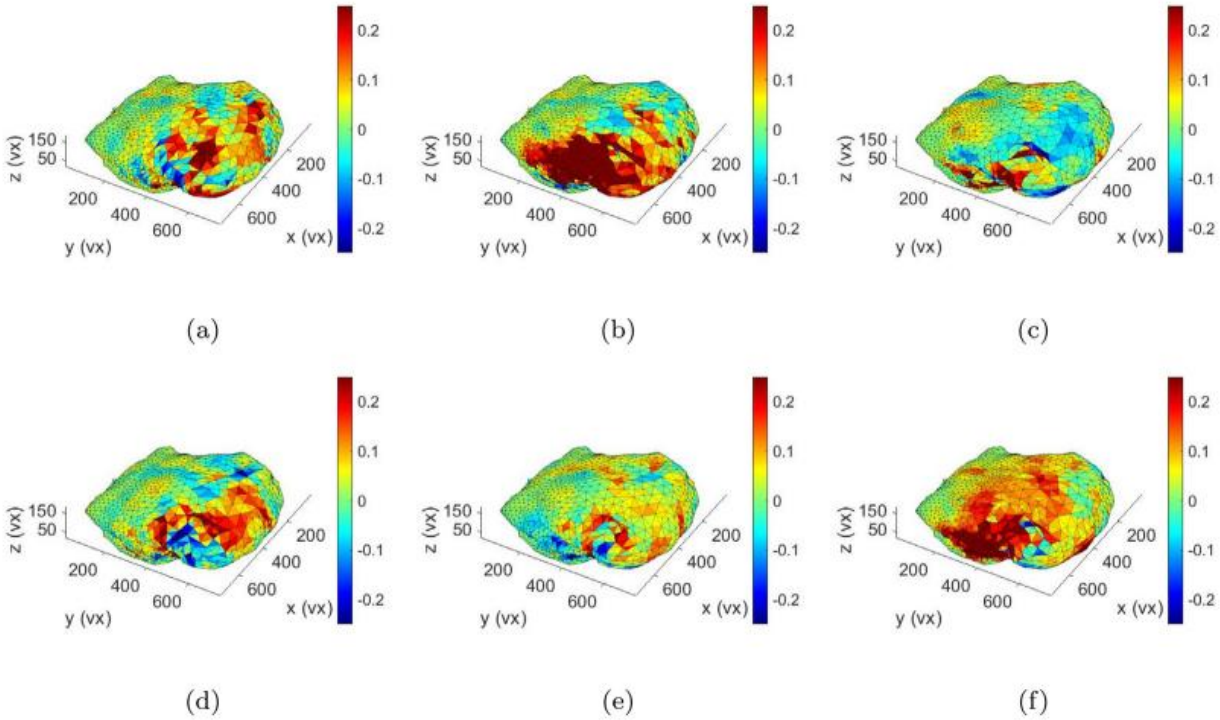

Figure 1: Green-Lagrange strain fields for the last DVC analysis displayed on the mesh without skin. (a) E_{xx}, (b) E_{yy}, (c) E_{zz}, (d) E_{xy}, (e) E_{xz} and (f) E_{yz} components. The soft tissue underwent large strains (including shear in particular in the inframammary fold) up to 25% in magnitude [2].

Discussion and Conclusion

The present study showed the capacity of FE-based DVC to faithfully capture large deformations of hard/soft tissues. The measured displacement field was considered realistic since the measured RMSE was less than the spatial resolution of the analyses (17 voxels). However, only one sample was studied and the gravitational forces were not included in the regularization scheme. The absence of repeated scans also implied to use an *a posteriori* estimation of the kinematic uncertainties. Last, to be compatible with clinical imaging techniques, further studies are thus required to consider the same method using MRI-scans, more samples and including gravity.

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