Equilibrated Warping: Finite Element Image Registration with Equilibrium Gap Regularization

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Image processing, in particular motion tracking, is playing an important role in biomedical engineering and in other domains such as materials and mechanical engineering. However, despite important progress made in the past decades, robustness, efficiency and precision of the existing methods must still be improved to translate them into medical and engineering applications [1].

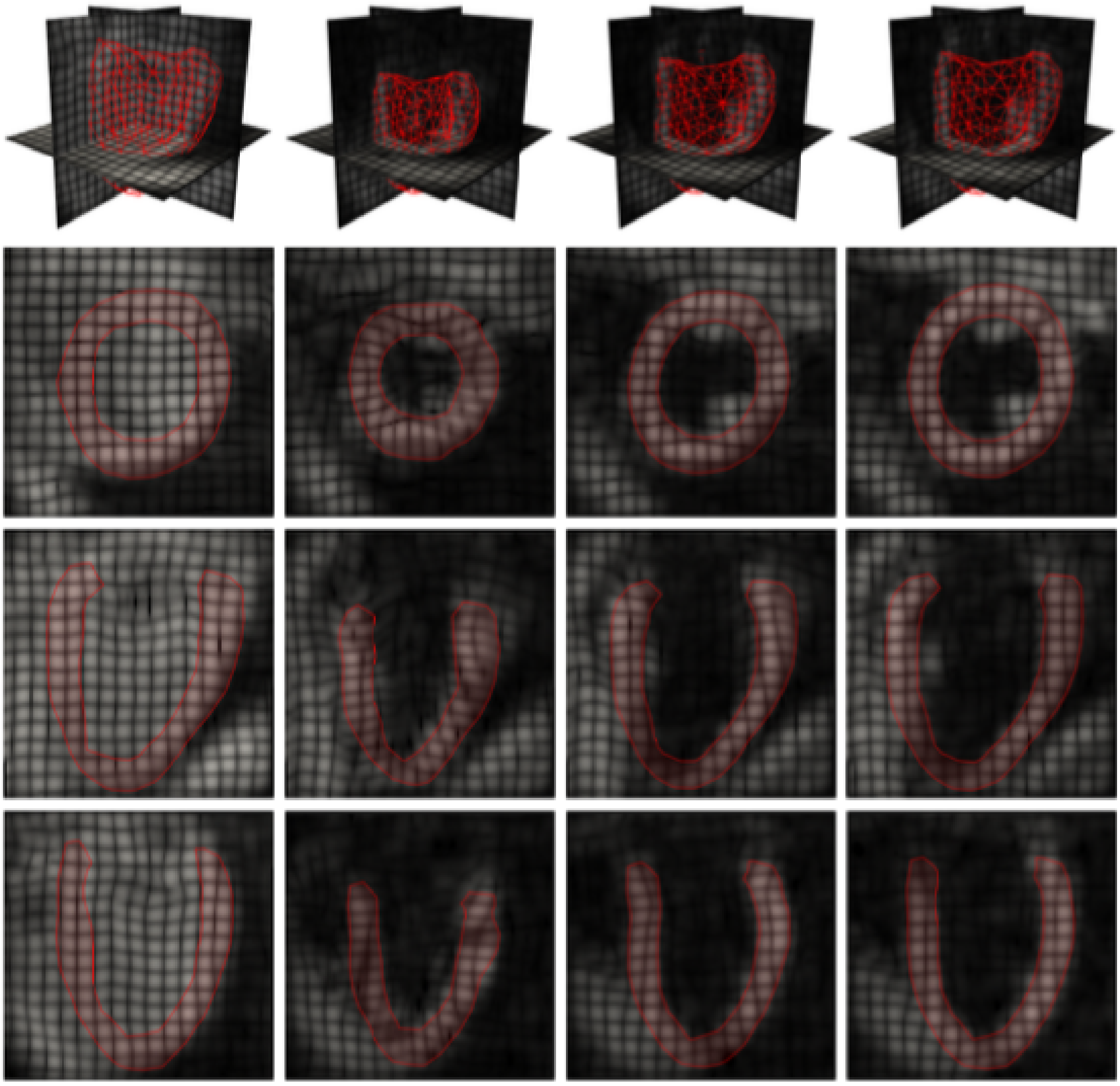
Equilibrated Warping is a novel image registration approach, based on the finite element method and the equilibrium gap regularization [2]. The finite element method is used to formulate the image registration problem, i.e., to find the displacement field that best match the source and target images, allowing to ensure some regularity to the solution. However, because of image limited resolution and noise, this problem is ill-posed, and require regularization. The equilibrium gap regularization essentially penalizes any deviation from the solution of a hyperelastic body in equilibrium with arbitrary loads prescribed at the boundary [3]. It thus represents a regularization with strong mechanical basis.

In the presentation, we will first describe the consistent linearization and discretization of the regularized image correlation problem. On simple synthetic images examples, we will show that the equilibrated warping method is effective and robust: regularization strength and image noise have minimal impact on motion tracking, especially when compared to strain-based regularization methods such as hyperelastic warping, or methods based on incompressibility constraint. We will also show results of the equilibrated warping method applied to in vivo tagged (3D CSPAMM, see Figure) and untagged (CINE) cardiac magnetic resonance images of a healthy volunteer: the method allows to extract main deformation features of the left ventricle, including radial thickening, circumferential and longitudinal shortening, as well as ventricular twist. It is also able to extract finer features of deformation, such as (i) larger radial strains in the free wall compared to the septum (because of the right ventricular pressure, this is only seen in untagged images); (ii) longitudinal variations of the radial-circumferential shear strain from apex to base. Finally, we will show that equilibrated warping compares very well with other image registration methods on a public cardiac motion tracking challenge data [1].

[1] Tobon-Gomez, De Craene, McLeod, et al. (2013) "Benchmarking Framework for Myocardial Tracking and Deformation Algorithms: An Open Access Database." Medical Image Analysis 17(6):632–648.

[2] Genet, Stoeck, Von Deuster, Lee and Kozerke. "Equilibrated Warping: Finite Element Image Registration with Finite Strain Equilibrium Gap Regularization." Medical Image Analysis.

[3] Claire, Hild and Roux. (2004) "A Finite Element Formulation to Identify Damage Fields: The Equilibrium Gap Method." International Journal for Numerical Methods in Engineering 61(2):189–208.



$t = 17ms$ $t = 251ms$ $t = 486ms$ $t = 720ms$