Segmentation & Grid Generation for Numerical Simulations of LVAD with Patient specific Data

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Motivation

With the recent development of computational facilities and efficient numerical methods it is nowaday possible to perform large simulations. In the context of left ventricular assistance, these techniques allow to run patient-specific simulations giving the opportunity to understand the system and its interaction with the cardiovascular system in a complete non invasive way and opening the field of predicting surgery. In this study we focus on the anastomosis of LVAD to the aorta. Segmentation, geometry reconstruction and grid generation from patient-specific data (usually CT-scan) of this region remains an issue for multiple reasons: the presence of the device inducing noise and metallic artifacts, the resolution being not optimal and the images acquisition sometimes in a non aortic contrast phase (see Fig.1). We propose a general framework to overcome this problem and create suitable grids for numerical simulations.

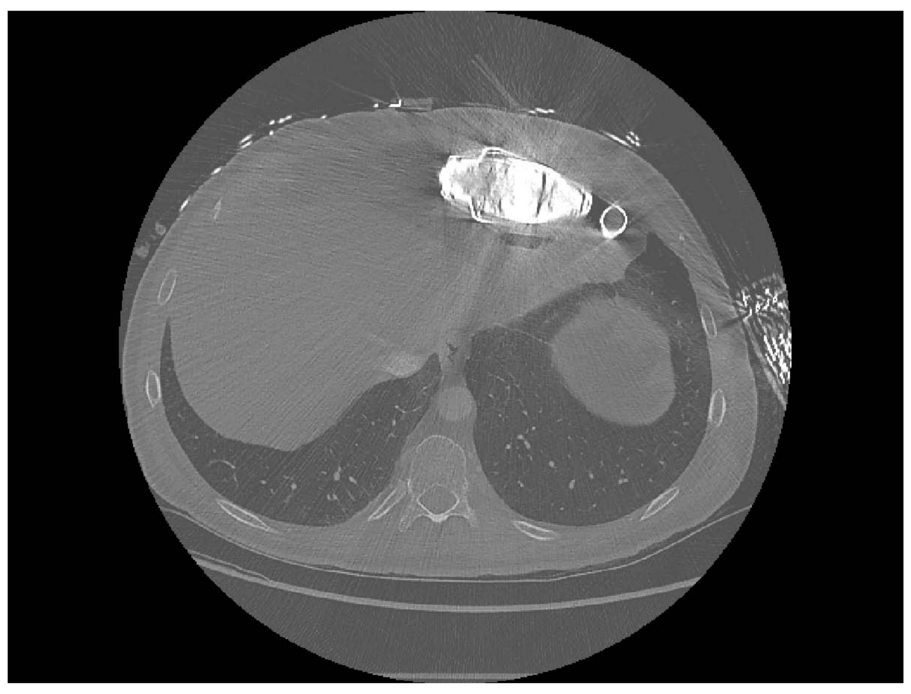
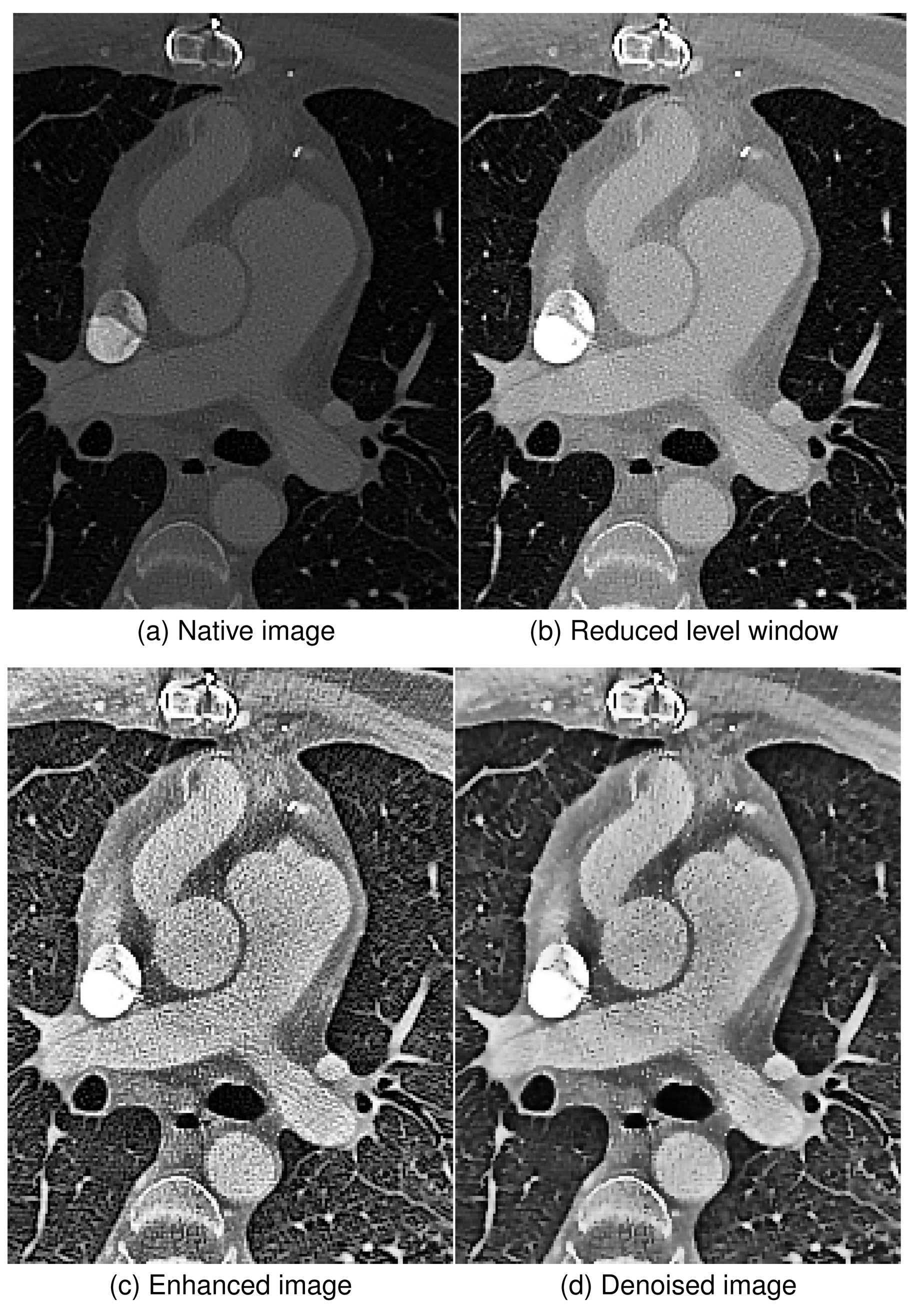


Figure 1: *CT-scan of a patient with a continuous flow LVAD. Note the noise and artifacts induced by the presence of the device*

DICOM images treatment

Preliminary treatment of images is performed by reducing the level window and enhancing the contrast of the greyscale image using contrast-limited adaptive histogram equalization. A gradient anisotropic diffusion filter is applied to reduce the noise (see Fig.2).

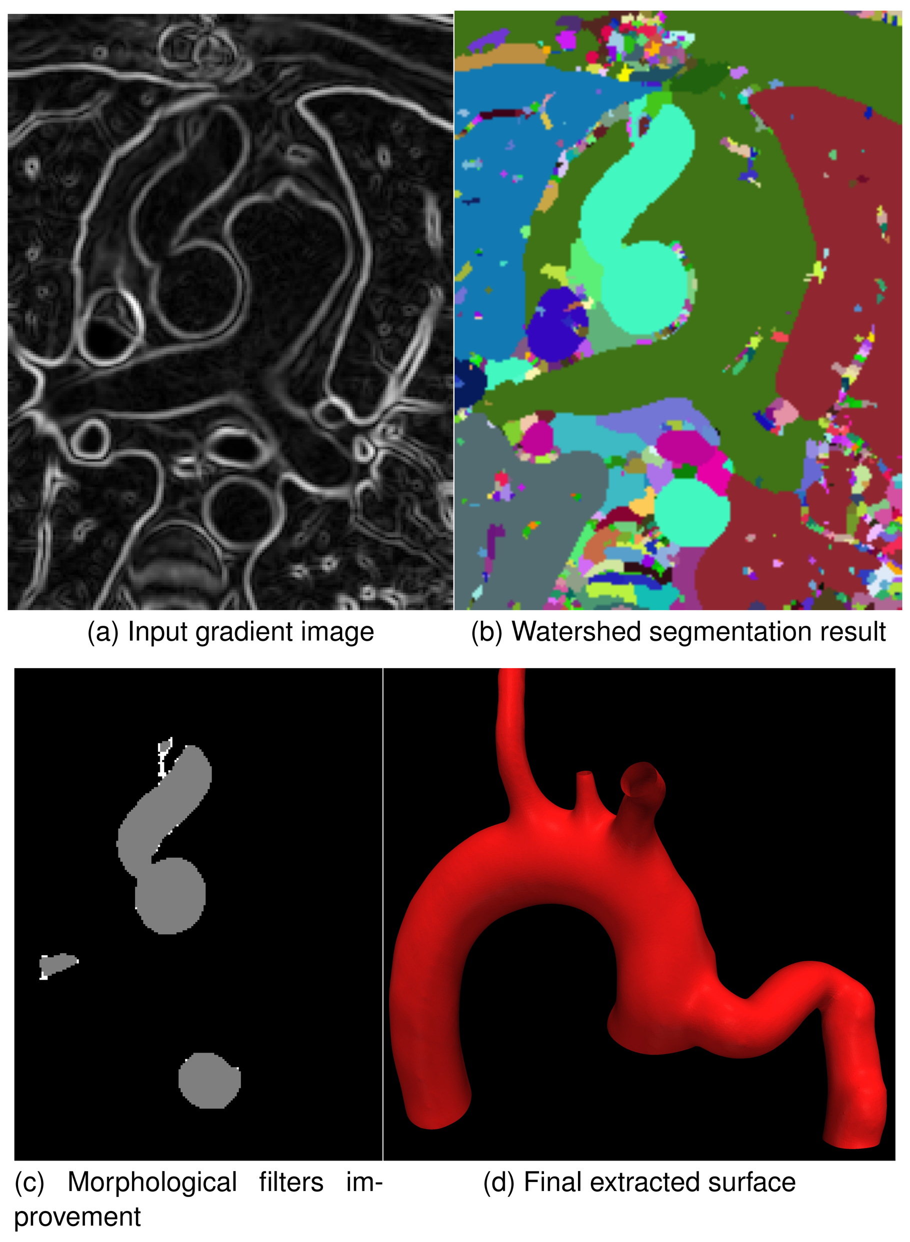


(a) Native image (b) Reduced level window (c) Enhanced image (d) Denoised image

Figure 2: *Effects of the different filters applied to the DICOM images seen at the level of the anastomosis between the outflow cannula of the LVAD and the aorta*

Segmentation

The gradient of the previously treated images is then calculated and the watershed segmentation algorithm is applied to the result. To improve the obtained segmentation mathematical morphology filters are then performed and the final surface is extracted. This is done using the InsightToolKit library (`www.itk.org`). These techniques are powerfull and reliable but also user-dependent, i.e., the choice of the value of the different parameters determines the quality of the final result.



(a) Input gradient image (b) Watershed segmentation result (c) Morphological filters improvement (d) Final extracted surface

Figure 3: *Segmentation procedure*

Grid Generation

The grid, created from the geometry, is composed of two parts: the fluid (blood) and the structure (arterial wall). The geometry allows to create the mesh that corresponds to the fluid, but the entire arterial wall is not visible on CT-scan so that the mesh for the structure is built as a function of the local diameter of the vessel. Since the diameter of the different vessels may vary significantly, the size of the tetrahedra that compose the grid has to be adapted. This is done by refining the grid as a function of the local diameter (see Fig.5). The software used is the Vascular Modeling ToolKit (`www.vmtk.org`).

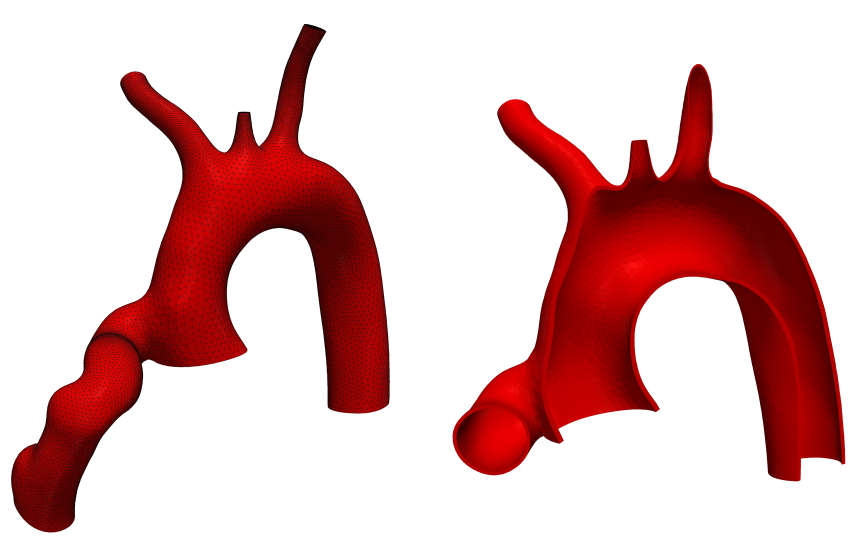


Figure 4: *Fluid and solid mesh*

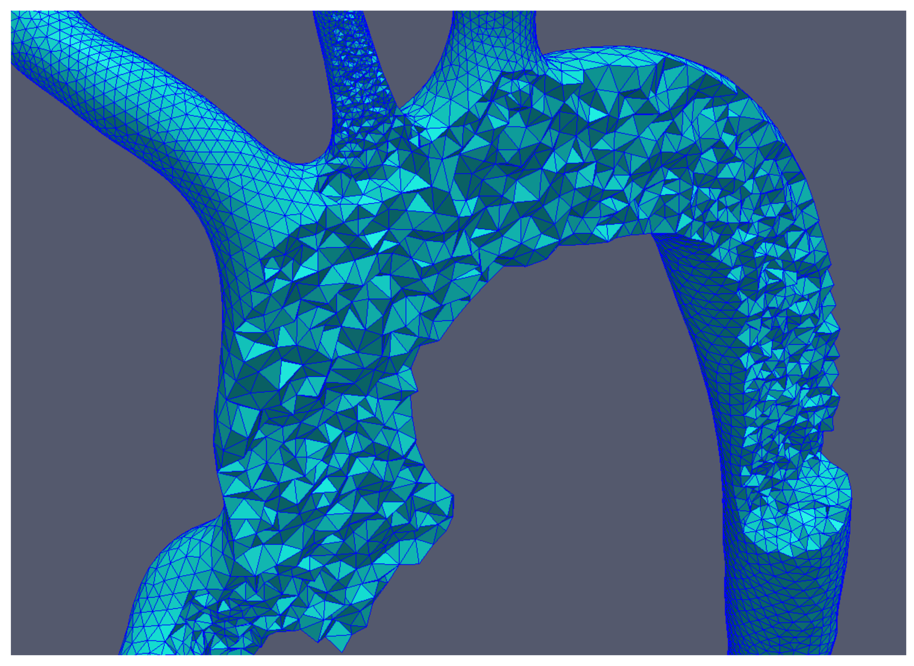


Figure 5: *Volumetric grid.*

Numerical Simulations

We present here a simulation performed using these grids. It is obtained by using LifeV (`www.lifev.org`), a high perfomance finite element library that allows to solve the 3D Navier–Stokes equations and to take into account fluid-structure interactions. Simulations are performed on clusters, e.g. Blue Gene/P (IBM) or Cray XT4 (Cray Inc.). In this particular case the aortic valve is assumed as closed so the whole influx comes from the cannula of the LVAD. The interaction with the entire cardiovascular system is modeled by a geometrical multiscale technique that couples the 3D model with a 1D tree model of the rest of the cardiovascular system.

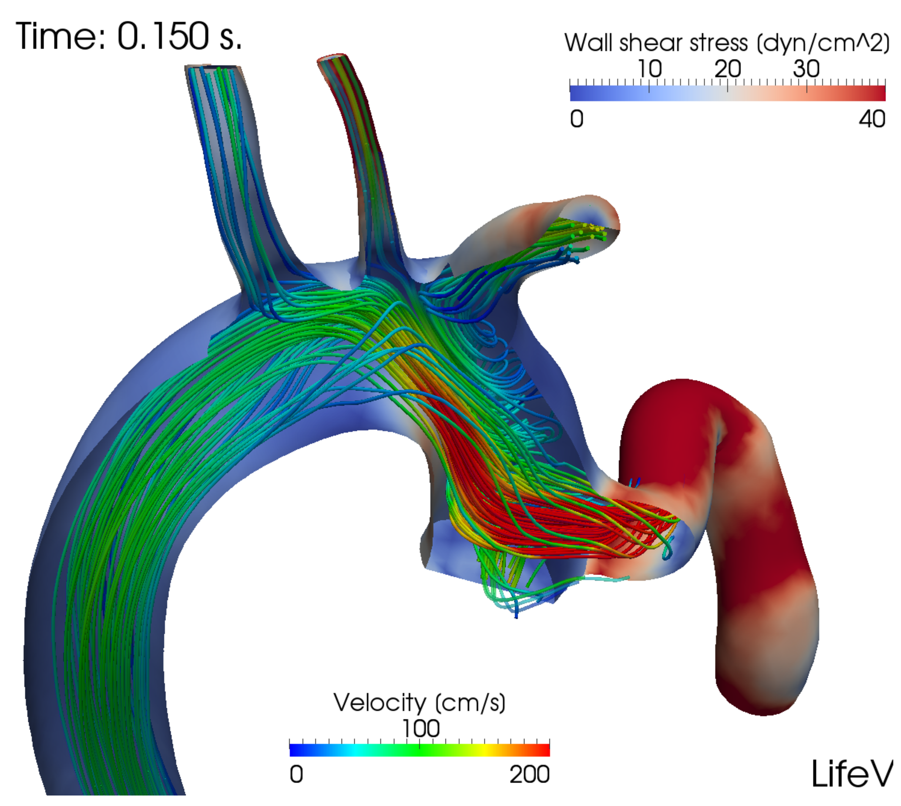


Figure 6: *Numerical results. Posterior view*

Results

The method is tested on five different patients with left ventricular assistance and who underwent a CT-scan exam. The anastomosis area is recovered and the generated grids are suitable for numerical simulations on four patients. On one patient the method failed to produce a good segmentation because of the small dimension of the aortic arch with respect to the image resolution.

Conclusions

The described framework allows the use of data that could not be segmented by standard automatic segmentation tools. In particular the computational grids that have been generated are suitable for simulations that take into account fluid-structure interactions. The presented method features a good reproducibility and fast application.

Acknowledgement
FNS Grant 323630-133898, Mathcard ERC-AG 227058