Method for Constructing Rapid Prototyping from MR Data

C. Arrieta[1,2], S. Uribe[2,3], C. Sing-Long[1,2], J. Ramos[4], A. Vargas[5], P. Irarrazaval[1,2], and C. Tejos[1,2]

[1]Department of Electrical Engineering, Pontificia Universidad Catolica de Chile, Santiago, Chile, [2]Biomedical Imaging Center, Pontificia Universidad Catolica de Chile, Santiago, Chile, [3]Department of Radiology, Pontificia Universidad Catolica de Chile, Santiago, Chile, [4]Department of Mechanical Engineering, Pontificia Universidad Catolica de Chile, Santiago, Chile, [5]Department of Surgery, Pontificia Universidad Catolica de Chile, Santiago, Chile

Introduction: Rapid Prototyping (RP), also known as stereolitography, is a technology first introduced in mechanical engineering for producing three dimensional physical models. Recently, it has become an important tool for surgical planning, prosthesis manufacturing, assisting diagnosis and teaching purposes, as it allows building realistic replicas of biological structures. They are usually constructed in two stages. In the pre–processing stage, the structure is scanned using tomographic imaging technologies, e.g. Computed Tomography (CT), Magnetic Resonance Imaging (MRI), or laser surface scanners. When using tomographic images, they are segmented to select the object of interest, and the surface of that object is triangulated and imported into an STL (STereoLitography) format, process which is commonly done using commercial software. In the manufacturing stage, several thin layers of powder particles are, one by one, spread by a roller and then selectively bound together by printing heads that deliver continuous jets of a binding solution. When the printing process is finished, the unbound powder is removed and the model is infiltrated with a cyanoacrylate–based material. These techniques have been extensively used to plan bone surgery, e.g. maxillofacial surgery, in which CT is the preferred acquisition methods. There is an increasing interest in extending RPs to develop models of soft tissues or organs, for which MRI plays a fundamental role. In this case image segmentation becomes an important issue because of the low contrast between different structures. In cardiac MR (CMR) for instance, image intensities from the myocardium and liver are similar, making difficult to segment one from another, especially when image resolution is not enough to show their effective boundaries. Therefore, standard threshold based, region growing based or edge detection based segmentation tend to fail, making the image segmentation process extremely tedious as important human assistance is required. We propose the use of an implicit Active Contour technique to facilitate the segmentation process. Additionally, we present a home-made software toolkit which can perform the whole pre-processing stage (segmentation, surface triangulation and STL export). We evaluated our toolkit by constructing an RP of a pathological heart scanned from a standard CMR.

Methods: The CMR data corresponded to a whole heart b-SSFP sequence acquired on a patient who had a dilated right ventricle and pulmonary arteries. To improve myocardium to blood contrast and to reduce fat signal, T2 preparation and fat suppression techniques were used respectively. The data set was acquired and reconstructed with a isotropic resolution of 0.65 mm. Image segmentation of the data was carried on using a 3D version of the active contour without edges algorithm [1] implemented in Matlab (The Mathworks, Natic). In its 3D form, this algorithm deforms level set surface embedded in a higher order surface so that to capture de boundaries of an object of interest. The deformation process is governed by an optimization of the Munford-Shah functional [2], so that the image is partitioned into two homogeneous regions, being the boundary of those regions the desired segmentation. Once the boundaries of the heart were detected, the resulting surface was triangulated using a home-made Matlab implementation of the marching cubes algorithm [3], and subsequently exported into an STL format develop in the same home-made software. The resulting data was printed as an RP using 3D printing technology (Z-Corp). Segmentation results were compared with a standard threshold-based segmentation, as is commonly done in commercially available software for RP.

Results: As shown on Fig 1, the amount of spurious pixels included by a threshold-based segmentation (Fig 1a) is considerably higher than in the active contour-based segmentation (Fig 1b). Therefore the amount of human assistance needed to remove those spurious pixels is less for the latter case.

Additionally, our software toolkit allow us to triangulate the resulting surface, achieving a smooth surface render of the heart (Fig 1c), which was exported into a STL format and successfully printed into a RP model (Fig 1d).

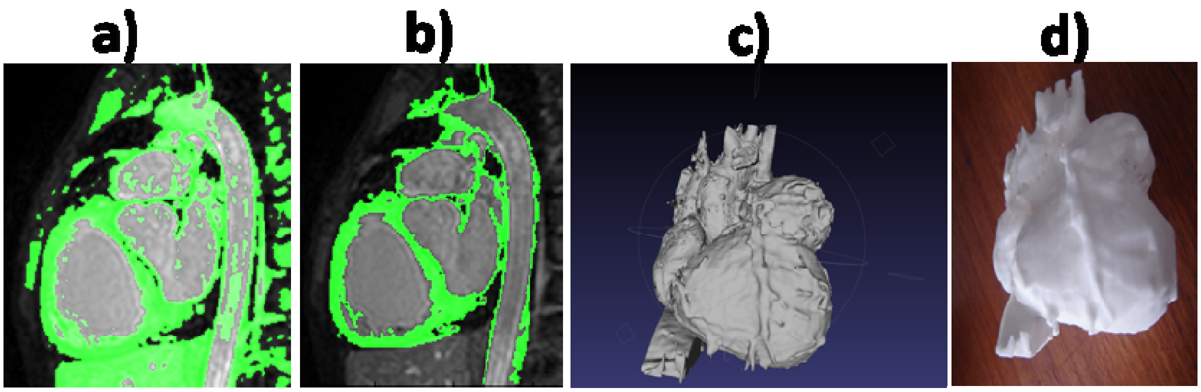

Figure 1: (a) image segmentation of a cardiac MRI based on thresholds. (b) The amount of spurious segmented pixels cab be reduce using Active Countors. (c) The proposed triangulation methods allows us to reconstruct smooth renders of the heart, and it allows us to print a realistic replica of the heart using RP technologies (d).

Conclusion: The proposed Active Contour-based algorithm significantly reduces the amount of human assistance needed to perform the segmentation of the MRI data. Some human assistance was still needed, but significantly less than that needed for thresholding methods. Our home made software toolkit allowed us to complete the entire process for building RP models, that is segmenting, triangulating, exporting to STL formats, and finally printing.

References: [1] T.F. Chan, L.A. Vese. IEEE Transaction on Image Processing 10(2), 2001. [2] D. Mumford, J. Shah. Communications on Pure and Applied Mathematics, 42(5), 1989. [3] W. E. Lorensen, et al. Computer Graphics, 21(4), 1987.