Impact of Surface Mesh Simplification on Hemodynamic Simulations

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Abstract. In this paper we present an approach to quantify the effect of triangular surface simplification on hemodynamic modeling. This work is organized in three parts. First, we briefly present the basic concepts inherent in hemodynamic modeling. Then, we describe the approach of triangular surface simplification. The simplified triangular surfaces are used as input as well as a parabolic inlet velocity profile to the hemodynamic modeling procedure. As a validation, the third part will be focused on two examples carotid blood flow characterization for a healthy patient and one with stenosis in the carotid artery. We quantified the differences between the generated models by evaluating the eucledean similarity, rate of change and RMSE between the measured and modeled velocity obtained with different mesh densities. We conclude with the important effect of re-meshing on the modeled results and we propose a minimum threshold of facets which ensures a good simulated velocity profile with a minimum error rate.

Keywords: hemodynamic modeling, triangular surface simplification, surface mesh simplification

1 INTRODUCTION

Triangular meshes are a very common representation for 3D surfaces. They enable the creation of highly detailed models and the application of various processing operations such as surface reconstruction, matching, shape modeling and analysis, denoising [1], mesh simplification [2], surface-modeling to measure for example the quality of the approximation of smooth surfaces from coarse meshes [3], to quantify local deformations in the LV of the heart [4] or to visualize vascular structures by exploiting the local curvature information of a given surface [5]. The present work is interested in investigating the effect of geometry on the quality of hemodynamic simulations in the vascular structure.

Although it is well established that that blood velocity may be affected by the vessel's resistance, pressure, viscosity and diameter, the present work is interested in investigating the effect of geometry (triangular meshes) on the quality of hemodynamic simulations in the vascular structure. We focused on triangular surface simplification of a given triangle mesh surface embedded in R^3. As a first step, we started by implementing a process of triangular mesh simplification. Afterwards, we used the different generated geometries as input of a hemodynamic simulator. An evaluation of the simplification effect on the quality of the simulation will be carried out.

The paper is organized as follows. The basic concepts inherent in hemodynamic modeling are depicted in the second section. In section three, the approach of triangular surface simplification is presented. The results obtained from real cases of the carotid artery of a healthy subject and a patient with a stenosis are outlined in section 4. An assessment of the effect of mesh simplification on the hemodynamic modeling is performed by computing some indicators (section 5). The results were then discussed and a conclusion summarizes the present work and presents our future perspective.

2 HEMODYNAMIC MODELING

The numerical method used in blood flow modeling is described by the following incompressible Navier-Stokes equations [6,7] :

$$\nabla . v = 0 \tag{1}$$

$$\rho \left(\frac{\partial v}{\partial t} + v . \nabla v \right) = -\nabla p + \nabla . \tau \tag{2}$$

In this framework, we generated some examples of simplified meshes. We chose three indicators (Rate Change RC, Similarity and RMSE) in order to quantify the differences between different velocity profiles. We concluded that simplification of surface triangular mesh has an important effect on the hemodynamic modeling results.

This work enabled us to propose a minimum threshold of facets which ensures a good simulated velocity profile with a minimum error rate. This threshold is defined as the number of facets by unit of surface, and the proposed value is 15 facets by cm^2. Using a number of facets bigger than this threshold does not significantly improve the quality of the velocity profile obtained but will result in a significant increase in computation time. In the near future, we want to (i) analyze the relation of this threshold with the other variables considered as constant in this work, and (ii) locally remesh the surface to optimize velocity profile simulation.

To improve the quality of our results and to cover the majority of cases we needed to study many real cases and to propose a flexible arterial model for validation. The principal limitation of this work is the reference velocity obtained by Doppler Ultrasound measurement. We are now working with another type of data characterized by a satisfying spatial resolution and a great number of velocity measure points obtained from 3D phase contrast MRI.

7 CONCLUSION

The effect of surface simplification on the quality of hemodynamic simulations was investigated in the present study. We fixed all hemodynamic parameters and we used only a parabolic velocity input. Three indicators were computed in order to quantify the effect of the mesh surface variation on velocity profile. To validate our findings, we performed a hemodynamic analysis on the healthy patient and the one with stenosis.

The first results enabled us to propose a minimal threshold in number of facets per unit surface, which ensures an acceptable simulated velocity profile. To improve and confirm our results, we are now working to enrich our patient database, integrate other geometric and hemodynamic parameters and above all to resort to more accurate measurements of velocity profiles such as MRI.

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