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Technical faculty "Mihajlo Pupin"
Zrenjanin

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International Conference

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Serbia, Zrenjanin, October 26, 2012

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TECHNICAL FACULTY ”MIHAJLO PUPIN”
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# INTRODUCTION

Information Technologies and Internet as a part of Computer science creates new approaches and perspectives, new models and numerous services, which opens up and makes use of the world of information and symbolized knowledge. Advances in Information technology, including the Internet, have dramatically changed the way we collect and use public, business and personal information.

The 1st **International Conference on Applied Internet and Information Technologies** is an international refereed conference dedicated to the advancement of the theory and practical implementation of both knowledge of Information Technologies and Internet and knowledge of the special area of their application.

The objectives of the **International conference on Applied Internet and Information Technologies** are aligned with the goal of regional economic development. The conference focus is to facilitate implementation of Internet and Information Technologies in all areas of human activities. The conference provides forum for discussion and exchange of experiences between people from government, state agencies, universities and research institutions, and practitioners from industry.

The key Conference topic covers a broad range of different related issues from a technical and methodological point of view, and deals with the analysis, the design and realization of information systems as well as their adjustment to the respective operating conditions. This includes software, its creation and applications, organizational structures and hardware, different system security aspects to protocol and application specific problems. The Conference Topics are:

- Information systems
- E-commerce
- Internet marketing
- Computer networks and data communications
- ICT Support for decision-making
- Embedded systems and robotics
- Customer Relationship Management
- Data and system security
- Software engineering and applications
- Reliability and maintenance
- Business intelligence
- Process assessment and improvement
- ICT practice and experience

The Conference Organizing Committee would like to thank for the support and cooperation to the Regional Chamber of Commerce Zrenjanin, BIZ – Business Incubator Zrenjanin, University of Novi Sad and Provincial Department of Science and Technological Development.

Special thanks to the authors of papers, reviewers and participants in the Conference who have contributed to its successful realization.

**President of the Organizing Committee**
**Ph.D Borislav Odadžić**

Zrenjanin, October 2012

*We are very grateful to*

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*Autonomous Province of Vojvodina,*
*Republic of Serbia*

*for financial support in preparing the Conference Proceedings and organizing the Conference.*

# CONTENTS

# Remote Visualization of Finite Element Calculation Results in Vascular Interventions Decision Making

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**Abstract - Paper presents an overview of software platform used by cardiologist in remote visualization of finite element calculation results in order to study of blood flow in human carotid arteries. Finite element solver PAK-F is used for the calculation of viscous fluid flow. Thus, governing equations of fluid flow are presented. The geometry of carotid artery bifurcation is obtained through the reconstruction based on images from CT scanner. Simulation of blood flow through the carotid artery bifurcation is conducted on a realistic three-dimensional patient-specific geometry. Developed software platform is tool which can give useful on site inputs to cardiologists. They determines if some cardiac intervention is required and in which moment of plaque development.**

## I. Introduction

Atherosclerosis is one of the most widespread diseases that affecting blood vessels in the human body. Artery bifurcations are among the most frequent site affected by atherosclerosis, being involved in up to 20% of percutaneous interventions. Several studies on the distribution of atherosclerotic plaques in human arterial systems have shown that atherosclerosis occurs predominantly at certain location of the vascular tree where the arteries have relatively complex geometry that result in disturbed blood flow behavior. In these regions, complex hemodynamic conditions dictate the localization and progression of atheroma. The studies [1-4] shows that very responsible flow-related hemodynamic factor affecting the distribution of atherosclerosis are low or reversed wall shear stress. Computational fluid dynamics (CFD) is an area of fluid dynamics that can be applied to study the hemodynamic factors in human body. Over the years, mathematical modeling, has established as a complementary to experimental approach in investigating clinical problems as well as predicting the biomechanical behavior. The results of the finite element models may be trusted if they take into account all impacts, including the actual geometry of the domain. In other words, anthropometric variability of size and shape should not be neglected.

This paper presents a very effective methodology for remote visualization of finite element calculation results via internet. The main intention procedure generates valuable inputs to cardiologists in planning further treatment of patients with cardiac and vascular diseases.

## II. Methods

### A. Basic equations of incompressible viscous fluid flow

Differential equations that govern the blood flow [5-7] are the Navier-Stokes equation. Essentially, Navier-Stokes equation represents the second Newton's law applied to the mass of fluid in control volume. This set of equations is expanded with continuity equation of fluid flow.

Using Galerkin method, with appropriate interpolation functions and integration by volume of finite element, a matrix form of previous equations is obtained:

$$\mathbf{M}\dot{\mathbf{V}} + \mathbf{K}_{vv}\mathbf{V} + \mathbf{K}_{vp}\mathbf{P} = \mathbf{F}_v \tag{1}$$

$$\mathbf{K}_{vp}^T\mathbf{V} = 0 \tag{2}$$

Components of this matrix and vectors are:

$$\bar{\mathbf{M}}_{IJ} = \rho\int_V \mathrm{h}_I \mathrm{h}_J \, dV \tag{3}$$

$$\left(\bar{\mathbf{K}}_{\mathrm{vv}}\right)_{\mathrm{IJ}} = \int_{\mathrm{V}} h_{\mathrm{I}} v_{\mathrm{j}} h_{\mathrm{J,j}} \mathrm{dV} + \int_{\mathrm{V}} \mu h_{\mathrm{I,j}} h_{\mathrm{J,j}} \mathrm{dV} \tag{4}$$

$$\left(\mathbf{K}_{\mathrm{vpi}}\right)_{\mathrm{IJ}} = -\int_{\mathrm{V}} h_{\mathrm{I,i}} \hat{h}_{\mathrm{J}} \mathrm{dV} \tag{5}$$

$$\left(\mathbf{F}_{\mathrm{vi}}\right)_{\mathrm{I}} = \int_{\mathrm{V}} h_{\mathrm{I}} f_{\mathrm{i}}^{\mathrm{V}} \mathrm{dV} + \int_{\mathrm{S}} h_{\mathrm{I}} \left(-\mathrm{p}\delta_{\mathrm{ij}} + \mu v_{\mathrm{i,j}}\right) n_{\mathrm{j}} \mathrm{dS} \tag{6}$$

By grouping equations (1) and (2), system of differential equations is presented as:

$$\begin{bmatrix} \mathbf{M} & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \dot{\mathbf{V}} \\ \dot{\mathbf{P}} \end{bmatrix} + \begin{bmatrix} \mathbf{K}_{vv} & \mathbf{K}_{vp} \\ \mathbf{K}_{vp}^T & 0 \end{bmatrix} \begin{bmatrix} \mathbf{V} \\ \mathbf{P} \end{bmatrix} = \begin{bmatrix} \mathbf{F}_v \\ 0 \end{bmatrix} \tag{7}$$

The system of equations (7) is a symmetrical system of nonlinear differential equations of first order by unknown values in nodes $\mathbf{V}$ and $\mathbf{P}$ . The matrix $\mathbf{K}_{vv}$ (4) is nonlinear, since it depends on velocity.

Wall shear stress is a hemodynamic factor which has great importance to study the problem of blood flow. Wall shear stress is calculated using equation:

$$\boldsymbol{\tau}_W = -\mu \frac{\partial \mathbf{u}_t}{\partial \mathbf{n}}\bigg|_{wall} \quad (8)$$

where $\boldsymbol{\tau}_W$ is wall shear stress, $\mathbf{u}_t$ is tangential velocity and $\mathbf{n}$ is the direction of a unit vector normal to the wall at the moment.

### B. *In-house software PAK-F*

The in-house software package PAK-F [8] is developed by Laboratory for Engineering Software (University of Kragujevac, Faculty of Engineering, Kragujevac). It consists of modules for steady and transient incompressible fluid flow with heat transfer and is based on finite element method and the fundamental equations of viscous fluid flow.

The main program loops per time steps. Within this loop there is loop per iterations. Solving nonlinear equations of fluid flow (7) is performed iteratively. The size of unbalanced loads is determined in current iteration. It corresponds to the increments of speed and pressure. This procedure continues until convergence criteria are not satisfied or until corresponding increments of displacements and pressures are not become enough small.

Results obtained by PAK-F are printed in *. vtk file for post-process in software Paraview [9], as described in [10].

### C. *Mesh generation*

To apply the methodology of calculating the fluid flow hemodynamic parameters (blood) to the human's bifurcations, it is necessary to make a realistic patient-specific model. A schematic model of the carotid bifurcation is shown in Fig. 1. In order to create an analysis file for software PAK-F, it is necessary to create finite element model. Reconstruction of the geometry of blood vessels is conducted in the software Mimics, based on CT images of patient provided by Clinical Centre of Serbia (Belgrade). Multiblock approach is used in mesh generation [11]. Blocks are created by in-house software STL2BLOCK. Based on blocks, quadratic eight-node isoparametric elements are generated in IA-FEMesh [12] (Fig. 2).

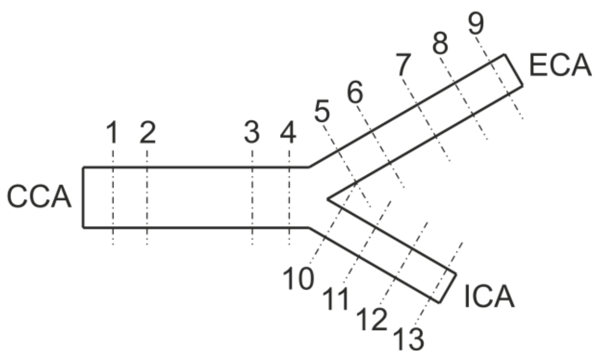


Figure 1. Schematic model of carotid artery bifurcation

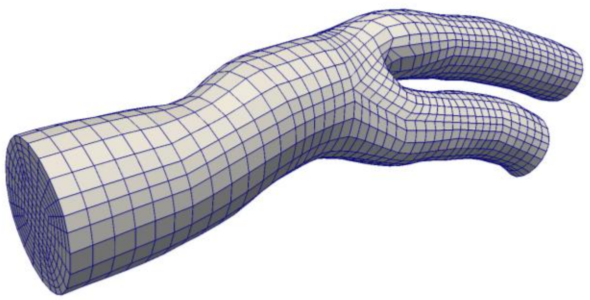

Figure 2. Fem model of carotid artery bifurcation

The calculation was performed in 30 steps (10 by 0.02s and 20 by 0.03s which gives in total 0.8s). The average flow velocity in the inlet is measured for each observed patient. Density of blood and coefficient of dynamic viscosity are adopted according to [13-16].

### D. *Remote Visualization with ParaView*

ParaView is an open-source, multi-platform client-server data analysis and visualization application. ParaView is developed to analyze extremely large datasets using distributed memory computing resources. The ParaView client runs on office computer (Clinical Centre of Serbia, Belgrade) while the server will run at the remote computing site (Laboratory for Engineering Software, Kragujevac), Fig. 3. Running ParaView remotely in a client-server configuration may involves establishing an ssh tunnel to the login node, lauching the ParaView server, connecting the server to the client over. The following text describes the steps to install ParaView on desktop and configure it to launch remote jobs within the ParaView GUI.

The first step is to install ParaView. Version 3.14.1 is currently the recommended version. The ParaView client is a serial application and is always run with the *paraview* command. The ParaView server is enabled with the *pvserver* command. For new server configuration ParaView will run an external command to start the server. The external command will be run using exec() (Posix systems) or CreateProcess() (Win32), so shell-specific functionality such as redirection or "&" cannot be used. A set of predefined and user-defined environment variables are used to communicate connection parameters.

To simplify the user experience, predefined ParaView server configurations for users from Clinical Center of Serbia is provided. This is performed with an external XML file. This page defines an XML schema for storing server configurations that is based on the existing functionality. Meaning of tags in xml file is given in the following text.

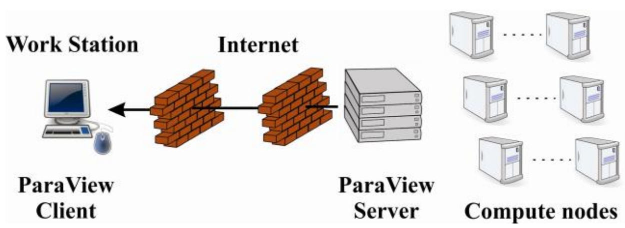


Figure 3. Calculation data remote visualization in Paraview via Internet

The <Servers> tag is the root element of the document, which contains zero-to-many <Server> tags. Each <Server> tag represents a configured server. The "name" attribute uniquely identifies the server configuration, and is displayed in the user interface. The "resource" attribute specifies the type of server connection, server host(s) and optional port(s) for making a connection. The "owner" attribute specifies where the configuration originated. Current valid values are "builtin", "site", or "user". The client uses this information to set policy, "builtin" and "site" configurations are read-only, "user" configurations are stored in per-user preferences.

The <CommandStartup> tag is used to run an external command to start a server. An optional <Options> tag can be used to prompt the user for options required at startup. Each <Option> tag represents an option that the user will be prompted to modify before startup. The "name" attribute defines the name of the option, which will become its variable name when used as an environment variable, and for purposes of string-substitution in <Argument> tags. The "label" attribute defines a human-readable label for the option, which will be used in the user interface. The optional "readonly" attribute can be used to designate options which are user-visible, but cannot be modified. A <Range> tag designates a numeric option that is only valid over a range of values. The "type" attribute controls the type of number controlled. Valid values are "int" for integers and "double" for floating-point numbers, respectively. The "min" and "max" attributes specify the minimum and maximum allowable values for the option (inclusive). The "step" attribute specifies the preferred amount to increment or decrement values in the user interface. The "default" attribute specifies the initial value of the option. As a special-case for integer ranges, a default value of "random" will generate a random number as the default each time the user is prompted for a value. A <String> tag designates an option that accepts freeform text as its value. The "default" attribute specifies the initial value of the option. A <Boolean> tag designates an option that is either on/off or true/false. The "true" attribute specifies what the option value will be if enabled by the user. The "false" attribute specifies what the option value will be if disabled by the user. The "default" attribute specifies the initial value of the option, either "true" or "false". An <Enumeration> tag designates an option that can be one of a finite set of values. The "default" attribute specifies the initial value of the option, which must be one of its enumerated values. Each <Entry> tag describes one allowed value. The "name" tag specifies the value for that choice. The "label" tag provides human-readable text that will be displayed in the user interface for that choice. A <Command> tag is used to specify the external command and its startup arguments. The "exec" attribute specifies the filename of the command to be run. The system PATH will be used to search for the command, unless an absolute path is specified. The "timeout" attribute specifies the maximum amount of time (in seconds) that the client will wait for the server to start. The "delay" attribute specifies a delay (in seconds) between the time the startup command completes and the time that the client attempts a connection to the server. <Argument> tags are command-line arguments that will be passed to the startup command. String substitution is performed on each argument, replacing each $STRING$ with the value of a predefined or user-defined variable. Arguments whose value is an empty string are not passed to the startup command.

The <ManualStartup> tag indicates that the user will manually start the given server prior to connecting. An optional <Options> tag can be used to prompt the user for options required at startup.

Configuration file is saved on location depending on operating system. On fig. 4 configuration interface for connecting with server is shown. Graphical user interface of Paraview in remote visualization of calculation data example is shown in Fig. 5. With ParaView cardiologists can quickly build visualizations to analyze analyzing data using qualitative and quantitative techniques. The data exploration can be done interactively in 3D or programmatically using ParaView's batch processing capabilities. In this way, doctors can have the full advantage of using a shared remote high-performance rendering without leaving their offices.

Velocity field along a streamlines in steps 1, 3 and 5 are shown in Figures 6, 7 and 8, respectively. Fluid velocity is changed depending on the region that is being observed on carotid artery bifurcation. On the internal carotid artery (ICA) it can be seen where there is a narrowing of blood vessels it leads to increased blood flow velocity.

Fig. 9 shows wall shear stress in step 05 of cardiac

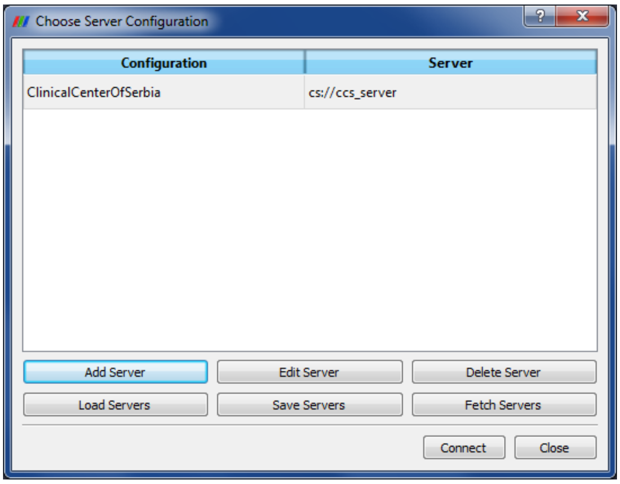


Figure 4. Configuration interface for connecting with server

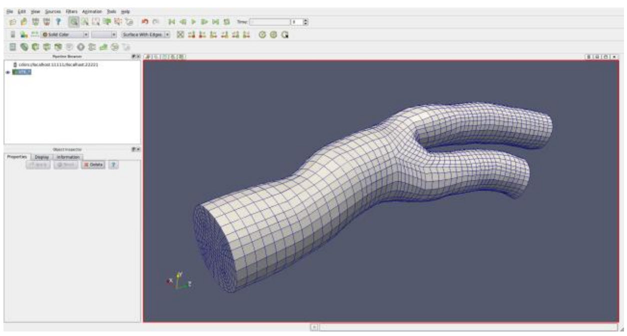

Figure 5. Paraview GIU in remote visualization of calculation data example

cycle. In this step there is maximum value of wall shear stress at peak systolic flow. On the external carotid artery (ECA) where cross section is bigger and flow velocity is smaller there are low values of wall shear stress. In these areas where wall shear stress has small values there is possibility for the occurrence of atherosclerosis.

## III. Conclusion

Provided case study illustrates the application of PAK-F in the study of hemodynamic characteristics of patient-specific carotid artery bifurcation. Calculation results are displayed client side (medics) by client server applications.

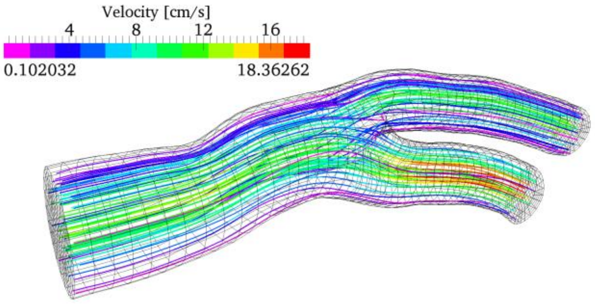


Figure 6. Velocity field in step 01

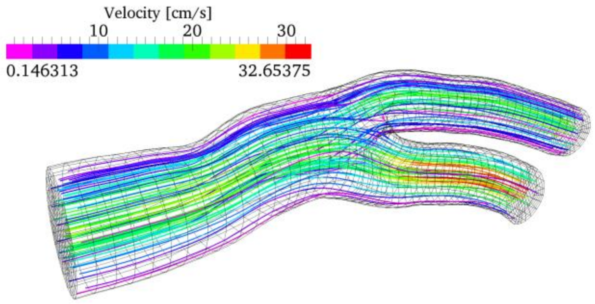


Figure 7. Velocity field in step 03

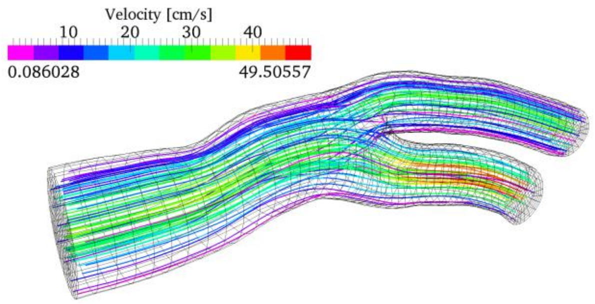


Figure 8. Velocity field in step 05

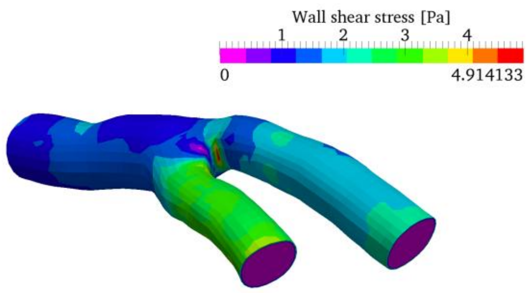


Figure 9. Wall shear stress in step 05

The combination of PAK-F with certain programs for pre-processing and post-processing gets a powerful tool in decision making. The previous considerations indicate that developed platform is software tool which can give useful inputs to cardiologists. They have clear view about insight of the blood flow through carotid artery bifurcation, so they can suggest surgical intervention or not.

Constriction problems of blood vessel can be successfully solved by installing the stents in positions with a possibility of total congestion of blood vessels. After placing the stent, blood vessel lumen and cross section is increased. Due to the rapid creating the model, calculation, and the presentation to cardiologists, approximate analysis of the coarse models may be conducted at each physical of individual patient. In this way it is possible to monitor the patient and determine the optimal moment in time of plaque development for stenting.

The ongoing research is oriented to the upgrade of software that will give a platform for coronary arteries and heart malfunctioning simulation.

The large variety of hardware, operating systems, and MPI implementations makes installing precompiled binaries of parallel ParaView impossible. Thus, to use ParaView on a parallel server, user has to compile ParaView from source. The server is a parallel MPI program that must be launched as a parallel job. The most common way is to use the *mpirun* command.

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