Comparative Visualizations of Noisy and Filtered Blood Flow from 4D PC-MRI Cardiac Datasets

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Abstract

Modern phase-contrast magnetic resonance imaging (PC-MRI) can acquire both cardiac anatomy and flow function in a single acquisition and deliver high quality volumetric and time-varying (4D) datasets which enable better diagnosis and risk assessment of various cardiovascular diseases. A good way to visualize blood flow from 4D PC-MRI datasets is to use animated pathlines through the anatomical context for representing the trajectories of the blood particles. Artifact correction is one crucial step in the processing pipeline of 4D PC-MRI datasets for representing the cardiac flow using pathlines, which in turn can reduce the overall quality of the useful information in the dataset. In this work, an approach is presented for comparative visualization of 4D PC-MRI datasets before and after artifact correction for qualitative analysis.

Index Terms: I.3.8 [Computer Graphics]: Applications—4D PC-MRI Blood-Flow Visualization.

1 Introduction

Blood flow analysis has long been used in the evaluation of various cardiovascular diseases. In modern days, the importance of better understanding and knowledge of physiological and pathological blood flow conditions is well-acknowledged and became easier thanks to the advent of various modern medical imaging techniques. Visual analysis of these data potentially leads to a better diagnosis and risk assessment of cardiovascular diseases. Furthermore, recent advancements in computational resources and graphics hardware have significantly improved the speed and quality of the modeling, computation and visualization of blood flow data [2]. In the medical domain, the increasing demand for easy flow analysis techniques has set up the research challenge to transfer the data into simple visualizations thus enabling the physicians to perform interpretation and decision making tasks [1].

4D (3D + time) PC-MRI is time-resolved three-dimensional phase-contrast magnetic resonance imaging, which acquires a time-dependent vector field of a patient's blood flow along with cardiac anatomy in a single acquisition. 4D flow MRI data have a complex structure with three spatial dimensions, three velocity directions of unsteady vector fields, and time steps within the cardiac cycles. This imposes the challenge of effectively representing visually the anatomical and functional information simultaneously, especially, in case of medical conditions associated with complicated flow behaviour. Among many options, an intuitive way of visualizing the temporal evolution of the blood flow velocity data over one or multiple heartbeats is to use pathlines that represent the actual path or trajectory of the time-varying non-stationary pulsatile flow. The particle tracing process considers massless particles, called seeds, strategically generated and emitted at user-defined points within the region of interest of the acquired data volume and follow the trajectories of the particles through the flow field over time.

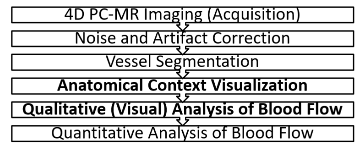

Figure 1: Our Processing Pipeline of 4D PC-MRI data

Recent works [2, 3, 5] discuss the standard processing pipelines for 4D blood flow data for analysis. There are three major steps in these processing pipelines: (1) acquisition, (2) preprocessing, and (3) visualization and analysis. Due to the physical nature of PC-MRI measurements, the resulting blood flow data contain a high amount of noise, artifacts and inaccuracies [6]. Furthermore, uncertainty or errors are introduced as the data are acquired, preprocessed and rendered. Effective visualization and quantitative analysis of this uncertainty is a major research challenge. Also, researchers have explored various types of artifact correction strategies and image enhancement methods like noise filtering and divergence-free corrections [7] for improving data quality. A drawback of these correction methods is that important information such as parts of the vessel and flow can be lost and error propagation can happen if the methods are not applied properly [5,7]. As validation of any obtained blood-flow data is difficult due to the lack of a ground truth, it is important to retain as much of the original information as possible after applying the noise filtering and artifact correction processes so that medical experts can effectively evaluate the data. Although some of the 4D flow features such as flow directionality, velocity profile, vorticity, disruptive flow patterns etc., and the effect of noise and artifact correction on them can be analyzed qualitatively, it is a much less explored domain compared to the supporting literature available for quantitative analysis [3]. Thus, qualitative analysis by visual comparison of the flow data before and after applying artifact correction can be very useful tools in the domain of medical visualization for determining acceptability of a correction method.

In this work, we present a new approach for qualitative analysis of the uncertainty introduced by noise filtering methods for 4D blood flow data. This comparative visualization approach simultaneously renders the blood flow as pathlines from the original noisy data and the corrected data in the same anatomical context using different rendering techniques. This will facilitate qualitative analysis of the results to determine acceptability of a correction technique based on the loss of useful information. Our approach adopts a number of comparative rendering styles to apply on the flow datasets and will be evaluated by domain experts to determine the best visualization for medical applications. This novel approach can be a very useful tool in the medical domain for comparative and uncertainty visualization of 4D blood flow. The next sections present a high level overview of our approach and some preliminary results.

2 Methodology

For comparative visualization of 4D PC-MRI datasets, we have adopted a processing pipeline presented in Figure 1. The commercial PC-MRI equipment acquire 4D flow datasets consist of several time steps spanning a single heartbeat, where each time step contains one

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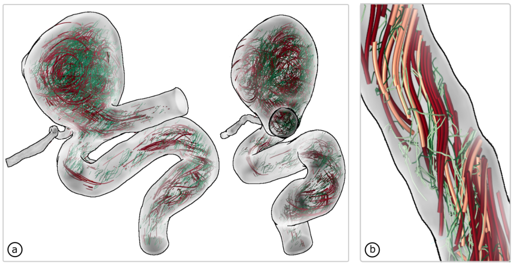

Figure 2: Comparative visualization of flow from noisy (represented by green colored thin lines) and filtered (represented by orange colored thick tubes) datasets in the same anatomical context.

magnitude and three phase difference images. Each image contains the velocity values in one of the spatial directions x, y and z. From these three components, a 3D velocity vector field V is reconstructed, which forms the basis of all further flow analyses. We have used a simple Gaussian smoothing filter on the flow datasets for creating initial test cases and preliminary results. Because of the generalized nature of our pipeline, any advanced noise and artifact correction technique such as, divergence filters can be used without changing any other step of the overall process.

For cardiac flow analysis in this work, we have considered the aorta and adjunct blood vessels as the region of interest as a large number of medical diagnosis is related to the blood flow through this main blood vessel carrying blood away from the heart to the whole body. The segmentation of the blood vessel is done manually and saved as a binary mask, which has two different applications in our processing pipeline. The first application is to apply the mask to the vector datasets to separate the region of interest, so that the seeding and pathline extraction is only done from inside the boundary of the blood vessel. The second application is using the mask as a geometric surface mesh representing the blood vessel, which is later rendered and visualized as the anatomical context.

For the comparative visualization, we extract pathlines from the original and filtered data. The pathlines are extracted from the vector fields of the 4D PC-MRI data using a high performance parallel implementation of the fourth order Runge-Kutta (RK4) method using general-purpose computing on graphics processing units (GPGPU) programmed in CUDA with C++. As a simple initial seeding strategy, a uniform distribution is used for generating random seed points in the region of interest.

For visualization of the segmented blood vessel, we rendered the geometric surface mesh in a 3D viewer environment implemented using GLSL with C++. For comparative visualization of the blood flow through the aorta, the pathlines extracted using RK4 from both original and filtered datasets are rendered with different styles and animated through the aorta for visualizing the time-varying flow and comparative analysis of uncertainty. The velocity magnitude for each of the flow datasets is represented using a different single-hue colormap for easier comparison and differentiation.

3 Preliminary Results

Our implementation is tested with real 4D PC-MRI data as well as simulated data. Although we tested and obtained results from two sets of real 4D PC-MRI datasets, we are not showing those results here for confidentiality reasons. Real datasets will be used in the final work after completion of ongoing clearance processes. For showing preliminary results, we have used a simulated dataset (blood flow through a vessel with an aneurysm) where the visualization challenges are the same. For simulating the nature of 4D PC-MRI, we have added Rician noise to the simulated blood flow. For domain expert feedback, a number of comparative visualization setups with combinations of different rendering styles is planned and one of these combination is used for the preliminary results. Fig. 2 illustrates the anatomical context of a partial blood vessel with an aneurysm, which is rendered as a surface mesh with a transparent ghost-view and a contour [4]. Then, two different sets of flow are rendered as two different sets of pathlines with distinctive visualization styles in the same anatomical context. This is a convenient setup for the comparative visualization of two different flow data in the same context with full user interaction and camera control. Our design choices are based on the data analysis in this domain as well as visual perception. For extracting the pathlines from the noisy data, we have used four times more seeds than the filtered data as the pathlines from filtered data maintain a more regular flow direction than the noisy data. A thin line representation with a green single-hue colormap is used for pathlines computed from the original noisy data while a thick tube representation with an orange single-hue colormap is used for pathlines obtained from the filtered data. As the original noisy data has more pathlines than the filtered data in this combination, this design choice is selected to use thin lines to represent the more scattered nature of the noisy data and thick tubes to represent the more regular nature of the filtered data. Fig. 2(b) illustrates how the use of distinctive visual cues minimizes the visual interference between the two sets of pathlines thus facilitating the comparison of the flow profiles in an integrated way.

4 Conclusion

This paper presents an ongoing work proposing a novel qualitative analysis approach for comparative visualization of uncertainty and effect of noise and artifact correction on 4D PC-MRI blood flow datasets, which has the potential to be developed as a very useful visual analysis tool for the medical domain. For completion of this work, we are going to employ recent and more advanced noise and artifact correction techniques in our processing pipeline, improve the design further, create a number of comparative visualization setups and evaluate their effectiveness based on domain expert feedback.

Acknowledgments

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