Virtual-Reality Based Visualization of Cardiac Arrhythmias on Mobile Devices

Joachim Greiner, Tobias Oesterlein, Gustavo Lenis, Olaf Dössel

Institute of Biomedical Engineering, Karlsruhe Institute of Technology, Germany

Abstract

Computer simulations and imaging of human physiology and anatomy are effectively used for diagnostics and medical treatments and are thus a focus of scientific research. Suitable representation of data is a critical aspect to achieve best results. Therefore, we developed an interactive visualization scheme especially for the representation of cardiac arrhythmias based on a conventional mobile device and virtual reality (VR) goggles (Google Cardboard and Samsung Gear VR) in combination with a game engine. The aim of this paper is to raise awareness for this new technique, evaluate its potential and propose a general workflow for such a visualization environment. The use of a conventional mobile device in combination with VR goggles creates a portable and low-cost system, equipped with enough processing power and pixel density for many types of applications. The user can interact with the data through head movement or a secondary controller. As current game engines support a wide range of additional input methods and controllers, the interaction method can be customized to fit the target audience. To evaluate this method, we conducted a survey with eight typical phenomena from the field of cardiac arrhythmias. The participants were asked to rate different performance aspects on a scale from one (very bad) to five (very good). All participants (N=27) rated the performance as fluent (median=5). Furthermore, most participants (70%) ranked the overall impression as very good (median=5). On the long run, the system can be used for education and presentations as well as improved planning and guidance of medical procedures.

1. Introduction

Cardiac arrhythmias often generate diverse and complex patterns. The usage of virtual reality (VR) allows an immersive and rich visualization beyond the traditional, two-dimensional representation approach. A suitable visualization can ease the process of analyzing clinical cases or simulation data. For educational purposes, a portable and interactive solution is particularly valuable. The goal of our visualization is to be portable, interactive and beneficial for the users' understanding of cardiac arrhythmias by providing a new perspective on the visualized data.

2. Methods

2.1. General Workflow: From Simulation to VR Visualization

Our general workflow (depicted in figure 1) begins with the conversion of raw simulation data to the Visualization Toolkit (VTK) file format [1] as a unified starting point for the visualization pipeline. VTK is a well known data format in the scientific community and many simulation frameworks already include export functions to the VTK format. In the next step, several preprocessing and data analysis steps are carried out, such as extracting the geometric region of interest or the analytical computation of desired quantities and properties for visualization. These quantities are then either mapped to the geometry surface or exported as a separate plot figure, which are then directly passed to the game engine. For these steps, the programs ParaView [2] and Matlab (R2016a, The MathWorks, Nattick, MA, USA) are used. Depending on the numerical method of the simulation, the original mesh is often much finer than needed to display the geometric and color coded information. Therefore, simulation-specific remeshing and simplification algorithms are applied to reduce the mesh sizes while ideally keeping the original geometric and color coded information. Depending on the topology and the mapped information on the surface, we either export the mesh with vertex colors or as a parametrised mesh with an additional texture map. For these steps, the open source mesh processing tool MeshLab [3] is used. Created geometry and color information are then imported into a game engine, such as Unity3D [4] or the open source project Unreal Engine [5]. Further specific work such as scene design, optimization for mobile applications, navigation between scenes and interaction are then directly implemented inside the game engine.

2.2. Hardware

An advantage of our general approach is that it is not limited to a narrow selection of hardware; any Google Cardboard or Gear VR compatible mobile phone (examples depicted in figure 2) can be used. With many mobile phones, we observed a high temperature after a short period of time. Most of those showed a particularly high temperature concentrated in a small spot, as depicted in fig-

 ISSN: 2325-887X DOI:10.22489/CinC.2016.311-527

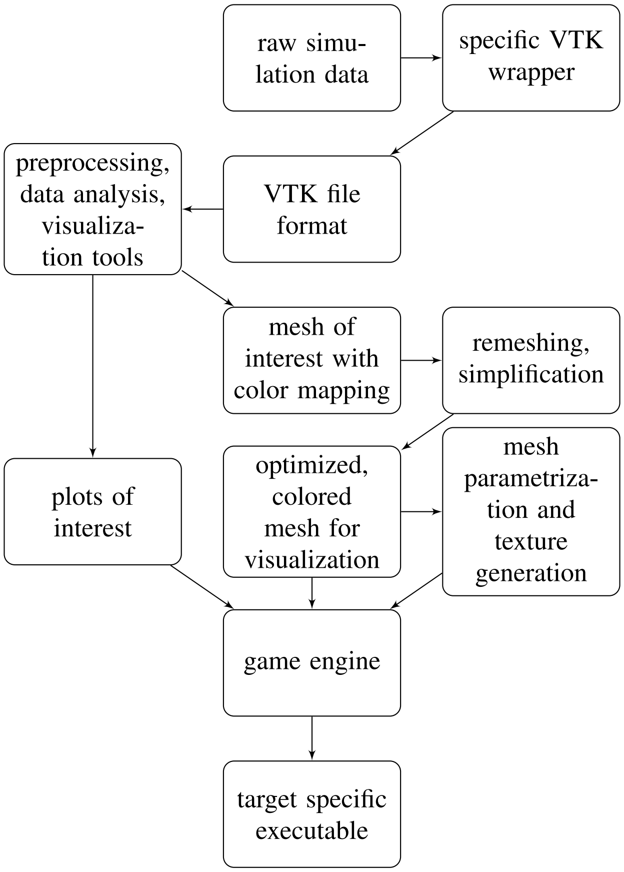


Figure 1. Semiautomatic workflow to create the executable visualization application.

Figure 2. Selection of used mobile devices, VR goggles and controllers.

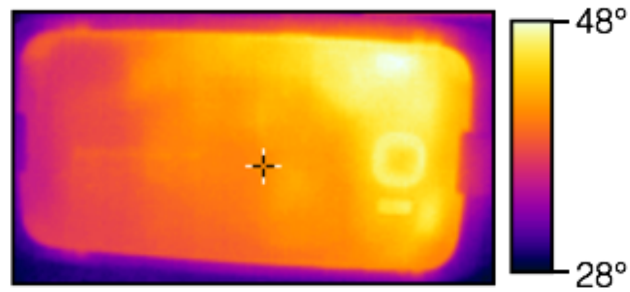


Figure 3. Temperature map measured with an infrared camera while running the application and streaming to a secondary display unit.

ure 3. The thermal problems in these cases can be solved by placing an additional heat pipe on the phones surface.

2.3. Specific Implementation

The implementations which were used to conduct the usability survey consisted of two VR goggles 'Samsung Gear VR' and the mobile phones 'Samsung Galaxy S6' and 'Samsung Galaxy S7'. They are based upon the gaming engine Unity [4], which allows application development in C#. We visualized eight different phenomena extracted from raw cardiac simulation data. Snapshots of these time dynamic movies are shown in figure 4.

Cardiac muscle contraction and fibre orientation: We implemented the results of a whole-heart simulation as well as a solution of an inverse fibre estimation problem. The results were generated with the simulation framework CardioMechanics, which uses a coupled finite-element approach to solve the multiphysics problem of the beating heart [6].

Atrial flutter and sinus rhythm: Three different visualizations of atrial flutter as well as one case with sinus rhythm were implemented. We used a framework with the fast-marching algorithm to simulate the electric excitation propagation on the surface of the atria [7]. The visualizations of atrial flutter include a visual cue pointing to the critical part of the tachycardia.

Intracardiac electrogram formation: We included also a computational analysis of a catheter with three mini-electrodes. A plot depicted four intracardiac electrograms calculated for the distal electrode and the three mini-electrodes. The solution to this electrophysiological problem was obtained by solving the bidomain equation with the simulation framework acCELLerate [8].

Ventricular ectopic beats: A body surface potential map displaying a regular and a ventricular ectopic beat over time was computed with a simulation framework using cellular automaton and an additional forward calculation [9]. The visualization includes a plot of the potential of a selected position on the torso surface.

The user can interact with the visualization through head movement, a touchpad integrated in the VR goggles or with a secondary controller. Possible interactions include rotation and zooming, pausing and resuming the animation, and fast-forwarding and rewinding the animation. To

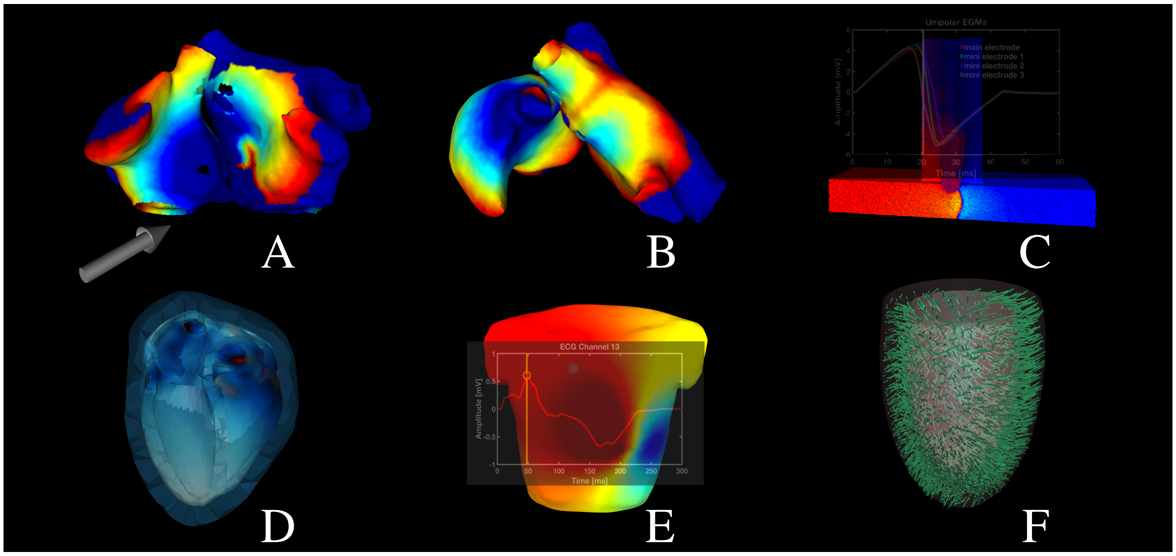


Figure 4. Implemented simulation scenarios. A: Atrial flutter with a visual cue pointing to the driver of the arrhythmia. B: Atria during sinus rhythm excitation. C: Slab of tissue with a mini-electrode equipped catheter, which is surrounded by blood. D: Whole-heart contraction simulation. E: Forward calculation of cardiac activity on the body surface. F: Cardiac muscle fibre orientation. Additional plots in the foreground depict resulting electrograms (C, E). The colorbar was adjusted for intuitive visualization of each scenario.

seamlessly switch between the different visualizations, the user can enter a selection menu with miniaturized models of all eight simulations.

2.4. Study Design

The participants (N=27) consisted of volunteers, which were primarily students with a technical background. All participants were instructed on the controls and briefly introduced to the physiological background of the displayed data. Afterwards, the participants were given as much time as they wanted to explore the different visualizations. The subsequent survey included questions about perceived resolution, motion sickness, intuitiveness of controls, benefit of VR for the understanding of the displayed data as well as the overall impression of the implementation. Each aspect had to be assessed by marks from one (very bad) to five (very good). The exact questionnaire is depicted in table 1.

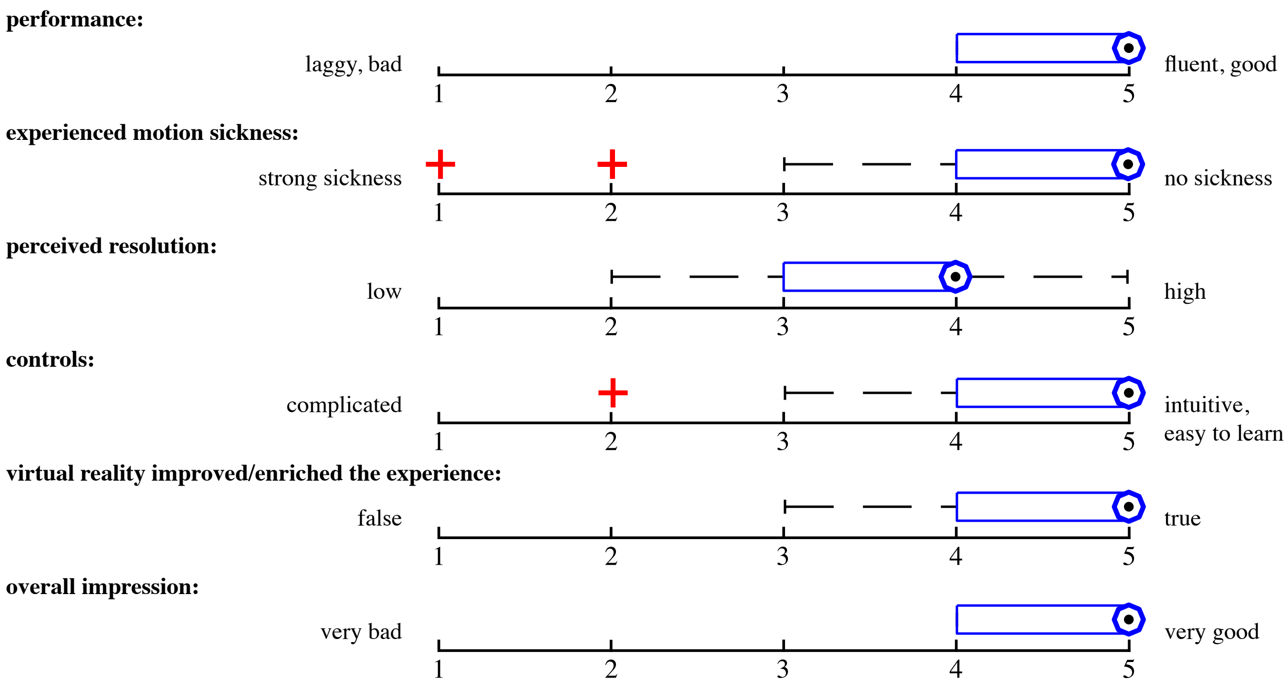
3. Results and Discussion

Our application was able to render the eight implemented visualizations with up to 150.000 vertices while simultaneously streaming to a secondary monitor with a stable framerate of 60 frames per second. The quantitative results and a boxplot of the survey are shown in table 1. All participants stated a fluent or almost fluent performance (median=5). Further, most participants stated that the use of VR improved the learning experience (median=5). We believe that immersive VR visualizations are particularly useful in a complex visualization task, such as the orientation of cardiac muscle fibre during contraction. While the majority (70 %) of the participants stated they experienced no motion sickness, eight participants (30%) experienced little to strong motion sickness. Furthermore, the perceived resolution was mostly ranked between medium and high (median=4). Both the resolution and the motion sickness is likely to improve with newer generations of mobile phone displays as well as with further habituation with VR products. Interacting with the visualization was experienced as easy to learn and intuitive for almost all participants (median=5). For instance, in our visualization implementation for atrial flutter, the user can see the heart anatomy in 3D in different modalities and the spread of cardiac depolarization, color-coded on the surface, as a function of time (4D movie). In the orbital mode, the camera can be rotated around the heart to visualize, for example, a depolarization wave traveling from one side to the other (e.g. anterior to posterior). In first person view, the user can move into the chambers of the heart and observe the depolarization wave from the endocardial perspective (e.g. catheters point of view). Thus, the understanding of the complex nature of a cardiac arrhythmia becomes more intuitive. Finally, all participants rated the overall impression of our visualization scheme with good or very good (median=5).

4. Conclusion

The findings suggest that our interactive and portable visualization approach has the potential of becoming a solution for an immersive representation of medical simulations and images in the field of cardiac arrhythmias.

Table 1. Boxplot and quantitative data of survey results. **Legend:** + (outlier), ⊢ — ⊣ (whiskers), ▭ (inter-quantile range Q3-Q1), ⊙ (median).



Issue:	**N(1)**	**N(2)**	**N(3)**	**N(4)**	**N(5)**	**mean**	**median (Q1,Q3)**
performance	0 (0%)	0 (0%)	0 (0%)	13 (48 %)	14 (52%)	4.5	5 (4,5)
motion sickness	1 (4%)	2 (7%)	2 (7%)	3 (11 %)	19 (70%)	4.4	5 (4,5)
perceived resolution	0 (0%)	4 (15%)	7 (26%)	14 (52 %)	2 (7%)	3.5	4 (3,4)
controls	0 (0%)	1 (4%)	1 (4%)	6 (22 %)	19 (70%)	4.6	5 (4,5)
VR benefits	0 (0%)	0 (0%)	1 (4%)	10 (37 %)	16 (59%)	4.6	5 (4,5)
overall impression	0 (0%)	0 (0%)	0 (0%)	10 (37 %)	17 (63%)	4.6	5 (4,5)

References

[1] Schroeder WJ, Lorensen B, Martin K. The visualization toolkit. Kitware, 2004.

[2] Ahrens J, Geveci B, Law C, Hansen C, Johnson C. Paraview: An end-user tool for large-data visualization. Visualization handbook 2005; 717-731.

[3] Cignoni P, Callieri M, Corsini M, Dellepiane M, Ganovelli F, Ranzuglia G. Meshlab: an open-source mesh processing tool. Eurographics Italian Chapter Conference 2008; 2008: 129-136.

[4] Unity game engine. www.unity3d.com. Accessed: 2016-07-30.

[5] Unreal game engine. www.unrealengine.com. Accessed: 2016-07-30.

[6] Fritz T, Wieners C, Seemann G, Steen H, Dössel O. Simulation of the contraction of the ventricles in a human heart model including atria and pericardium. Biomechanics and Modeling in Mechanobiology 2014; 13(3): 627-641.

[7] Loewe A, Poremba E, Krueger MW, Dössel O, Seemann G. Fast marching simulation of atrial excitation: Towards personalized ablation planning. In TRM Forum. 2013.

[8] Seemann G, Sachse F, Karl M, Weiss D, Heuveline V, Dössel O. Framework for modular, flexible and efficient solving the cardiac bidomain equations using PETSc. In Progress in industrial mathematics at ECMI 2008. Springer, 2010; 363-369.

[9] Potyagaylo D, Segel M, Schulze WHW, Dössel O. Noninvasive localization of ectopic foci: a new optimization approach for simultaneous reconstruction of transmembrane voltages and epicardial potentials. In FIMH, LNCS 7945. 2013; 166-173.

Address for correspondence:

Joachim Greiner
Institute of Biomedical Engineering
Karlsruhe Institute of Technology
Fritz-Haber-Weg 1 / D-76131 Karlsruhe / Germany
publications@ibt.kit.edu