Gradient based Volume Visual Attention Maps in Ray Casting Rendering

[abcd]Andoni Beristain, [abe]Luis Kabongo, [abf]Sabarinath Rajasekharan

[a]Department of eHealth and Biomedical Applications, Vicomtech
[b]eHealth Group, Bioengineering Area, Biodonostia Health Research Institute
[c]Computation Intelligence Group, Basque University (UPV/EHU)
[d]aberistain@vicomtech.org, [e]lkabongo@vicomtech.org, [f]srajasekharan@vicomtech.org

Abstract. This paper presents a method to naturally enhance spatial regions in ray casting volume rendering using a spatial importance measure inferred from the user's visual attention focus. This work presents three improvements over a former work of the author on Volume Visual Attention Maps in Ray-Casting rendering. These contributions are: a more accurate and realistic volume visual attention map definition, a watershed pre-segmentation guided visualization enhancement and the use of a generic two-dimensional transfer functions combined with the importance measure as opposed to the one-dimensional functions used in the previous work.

Introduction

In the last years, advances in medical imaging systems have permitted capturing dense volume data of high resolution, which in turn improves the diagnostic and treatment of the patients. One side effect of this increase in the accuracy is the higher amount of data that the specialist has to review, which combined with the limited amount of time available to analyze each data set, it makes manual image reviewing unviable. On the other hand, fully automatic data set analysis and segmentation could be much more efficient, but it is only available for very specific cases, both because of technical limitations and also because the specialist's particular requirements are not considered by the automatic procedure. Therefore, it seems that the most sensible approach would be to follow a user guided semiautomatic procedure, that is, an interactive procedure.

The medical specialist's trained eyes deliberately examine specific regions in the images searching for anomalies. And once an anomaly is spotted, he is also able to discriminate between pathology related anomalies from those artifacts due to noise in the image capturing procedure. This behavior is not exploited by the current medical image analysis applications.

Direct volume rendering approaches provide a higher perception of the spatial context and also permit depicting a higher amount of information in a single view than 2D approaches and 3D surface based rendering, therefore being a convenient method to analyze high resolution images quickly. In spite of it, achieving an appropriate visualization of the relevant features for the medical specialist, while occluding non interesting ones is a challenging and time demanding task.

This paper presents a ray casting based interactive visualization method for non-segmented data sets which uses a combination of a region importance metric, based on the user's visual attention, and an initial automatic segmentation, which in our prototype relies on the Watershed Transformation. The set of regions which are important for the user, i.e. they are the focus of the visual attention of the user, are highlighted over the rest of the data, while preserving the context information. Remark that, although in this work there is tight relationship between the visualization technique (i.e. ray casting) and the visual attention model, any algorithm could be used for the initial segmentation, given that it provides the same information as the Watershed Transformation and without needing to set any algorithm parameter.

This work is based on a previous work presented at the MMVR19 conference [3], and it proposes three improvements over it:

- Presents a more realistic 3D model of the visual attention for ray casting
- Uses the information about the set of homogeneous regions and their boundaries (i.e. gradient) present in the current data set (e.g. Watershed regions) to guide the creation of an importance measure of each data in the data element set from the visual attention model
- Uses an adapted ray casting algorithm, which employs a generic 2D transfer function (i.e. data and gradient based) for the basic rendering and a data voxel importance measure for the visualization enhancement.

Materials

In order to validate our approach, we have developed a prototype composed of several parts: a commercial non-intrusive eye-tracking solution provided by EyeTech, a region importance modeling module and the adapted GPU based ray casting based volume rendering module, implemented using ITK and VTK. For the initial GPU shader tests we have used AMD's RenderMonkey™ application. The data sets shown in the figures belong to the PANORAMIX data set from the OsiriX DICOM image sample sets.

Analogous to our previous work [3], in this prototype the eye-gaze based User Interface (UI) is used for two different purposes: first to identify the important regions of the data set interactively; and second for virtual camera control (e.g. zoom and orbit around the volume).

Methods

When viewing a scene, the eyes perform two kinds of operations called saccades and fixations [2]. Fixations are relatively stable eye focus points and correspond to human cognitive processes where we extract visual information that we process. Saccades on the other hand are unconscious rapid eye motions with no relationship to any cognitive process, and usually correspond to the eye motion between consecutive fixations.

We identify fixations to model the visual attention of the user, in the form of a Visual Attention Map (VAM). VAM are constrained to 2D, so for this particular case, we coined the term Volume Visual Attention Map (VVAM) to specify that we create a 3D model of the visual attention on a 3D dense data set visualized using a direct volume rendering approach using ray casting. These concepts are further discussed in our previous work [3].

In that former paper we depicted each fixation as a circle projection through the 3D data set, starting on the 2D fixation point in the image, where the values of the circle projection (i.e. a cylinder in 3D) corresponded to a Gaussian function on the distance to the centre.

The refinement proposed in this work not only considers the fixation position, but also what the user is perceiving, that is, what it is really being depicted, when performing a ray casting rendering. Usually, early ray termination is used in ray casting to stop any ray for going further when the accumulated opacity is close to the maximum, because the contribution of those later steps is not relevant for the final rendered value and to improve the efficiency. Therefore, in order to take into account what the user really sees and what not, for the VVAM computation, we apply an early ray termination to each fixation cylinder using the ray casting early ray termination information. This representation increases the accuracy and coherence of the VVAM and we have called it the early termination VVAM.

The early termination VVAM computation follows the next steps, illustrated in Fig. #1:

1. Identify fixations in 2D
2. Obtain the fixation cylinder input and output coordinates (including the early ray termination information from ray casting)
3. Add the fixation cylinder Gaussian values to the VVAM

The other important piece of the method is based on the use of an automatic region segmentation algorithm. For our experiments we used the Watershed Transformation [4], which provides a labeling of homogeneous regions, but any other alternative method could be used. We chose this method because it is a well known method which illustrates one of the main problems of automatic or semiautomatic segmentation algorithms, over-segmentation, which forces to further manual procedures to refine the results. Prior to the visualization step, we compute the Watershed Transformation of the input data set, producing an over-segmented result. The Watershed Transformation is performed on the gradient magnitude image which is also used by the ray casting algorithm to look-up in the 2D transfer function. For the GPU based ray casting implementation and due to hardware constraints, the number of regions has been limited to 256, performing region linking by conventional methods after the Watershed Transformation.

We then combine the VVAM and the Watershed Transformation in order to obtain an importance measure for every data element in the data set. This importance measure set is denoted as the importance map. The VVAM is constrained to the Watershed Regions. Following the Watershed Transformation analogy, the over-segmented Watershed Transformation is filled by the VVAM. Those Watershed regions filled by the VVAM in more than a certain threshold rate form the final importance map, which is used to enhance the visualization. See Fig. #2 for the method diagram. The importance map is stored as a 3D floating point single channel texture and it is provided to the ray casting algorithm.

This refinement of the VVAM to obtain an importance map is grounded in the belief that relevant regions for the user usually correspond to regions where there is a variation in the data set values which may or may not be easily perceptible by a conventional ray casting visualization. But if they are not clearly perceptible, they could benefit from region boundary based visual enhancement.

Some authors denote this concept as importance based rendering, but when referring to the way in which the enhancement of the important region is performed, it is commonly denoted as focus+context. The focus+context approach is concerned by the need to balance between focusing on one particular spatial region, the important region (our method is not limited to one contiguous region), while preserving some context information, which gives clues about the spatial configuration of the data set, and permits moving the focus of attention to a different region.

For the particular case of our prototype we alter the visual style of the important regions affecting the hue, saturation and opacity of them. This is a simple yet effective way to make a clear enhancement of important regions. We perform a conversion from the RGB color space to the HSV color space. Hue (H) is turned from the original to the opposite depending on the importance value. Saturation (S) and value (V) are set to the importance value. We also use a blending factor which controls the enhancement amount from a pure ray casting based to this importance map based. This blending factor can be modified interactively to provide additional context information in a final application setup. Fig. #3 illustrates the resulting rendering.

Like in our former work, eye tracking is also used to change the viewpoint around the data set and to zoom in and out, although the mouse can also be used. Nevertheless, from our experience, we have realized that for this task it is more natural to use the mouse. The mouse can be used to rotate or zoom on the data set viewpoint, while retaining visual focus of attention on the region of interest. In this sense, we have also found convenient the addition of a simple voice command based supportive UI, to toggle between zoom and rotation related mouse button mappings.

The workflow of our method follows the idea of the former work: the user selects a meaningful data set viewpoint, using either the eye-tracking or the mouse, and looks at the relevant regions. These regions start to become more visible than the rest. In order to refine the region or to select additional regions, the user selects another viewpoint and looks at the relevant regions. Combining the focus on different views, important regions can be spotted accurately and naturally.

Conclusions & Discussion

We have presented an interactive volume data set visualization method combining the visual focus of attention of the user and a prior knowledge of the data set, which provides several advantages over pure manual or automatic methods. On one hand, it takes into account the user’s particular requirements, intuitively specified by the visual focus of attention, and on the other hand, it is supported by an automatic procedure, which reduces the amount of user interaction required. This work is the continuation of the work presented at the previous edition of MMVR with three specific contributions related to the accuracy of the visual attention modeling, the inference of the data set regions’ importance for the uses and the way in which this information is used to enhance the data set visualization. The developed prototype validates the feasibility of the approach.

Just as we remarked in our aforementioned paper, we consider that this technique can increase the effectiveness and efficiency of ray casting volume rendering visualization, especially in the medical image visualization field. Effectiveness, because the VVAM could be stored along with the original data set, keeping track of the regions already reviewed and those which have not yet been reviewed, to avoid skipping any detail, and also be shared with other specialists as a communicative and even didactic purpose. Efficiency in terms of time and skill required to perform the visualization, because we expect this method to be quicker than conventional manual transfer function tuning in combination with manual region selection, and also more natural and intuitive, specially for the transfer function related visualization tuning. Unfortunately, at this moment, no studies are available comparing the use of our technique over current techniques in order to confirm and validate our assertions.

The validation of our VVAM based methods by means of user tests with medical experts is one of our next objectives. In fact, this method is one example of the broader work that we are carrying out on importance based rendering, combining the use of the visual focus of attention and direct volume rendering methods. Our applied research center, Vicomtech-IK4, is part of a health research cluster called Biodonostia, including a regional hospital. We are planning to perform our subject tests (i.e. realize repetitive tasks with our setup), with medical specialists from the hospital involved in Biodonostia. The purpose is to obtain a quantitative validation on one hand, in terms of performance gains over current methods, and on the other hand to obtain a qualitative measure in terms of the users’ acceptance of the method.

Several improvements are required in order to reach to a final prototype. We are mainly focused in refining the way in which the importance map is inferred from the VVAM and on visual styles used for the enhancement.

Finally, as highlighted in our above-mentioned paper, the migration of this method into a web based application is also part of our roadmap, using WebGL.

References

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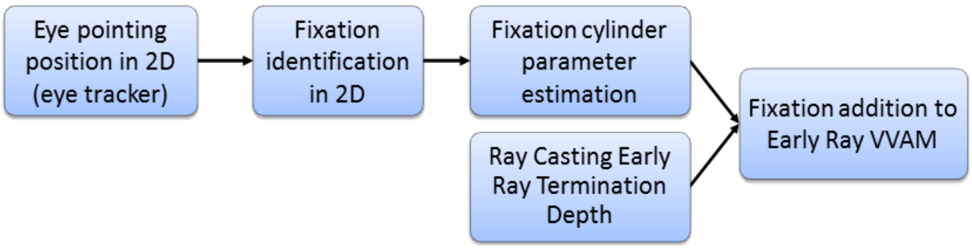
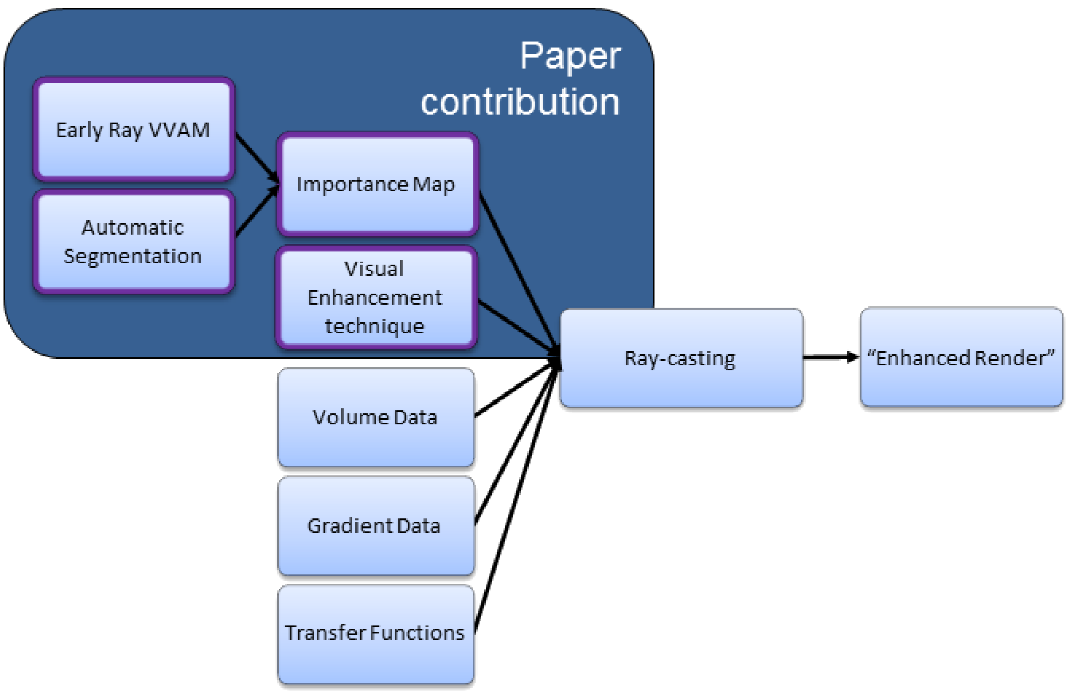
[2] A. Poole and L.J. Ball, “Eye Tracking in Human-Computer Interaction and Usability Research : Current Status and Future Prospects,” Encyclopedia of Human Computer Interaction, C. Ghaoui, ed., Idea Group, 2006.
[3] A. Beristain and J. Congote, “Volume Visual Attention Maps (VVAM) in Ray-Casting Rendering” Studies in health technology and informatics. J.D. Westwood et al. 2012, vol. 173, pp. 53-57
[4] S. Beucher and C. Lantuejoul. “Use of Watersheds in Contour Detection”, International Workshop on Image Processing: Real-time Edge and Motion Detection/Estimation, Rennes, France, 1979.

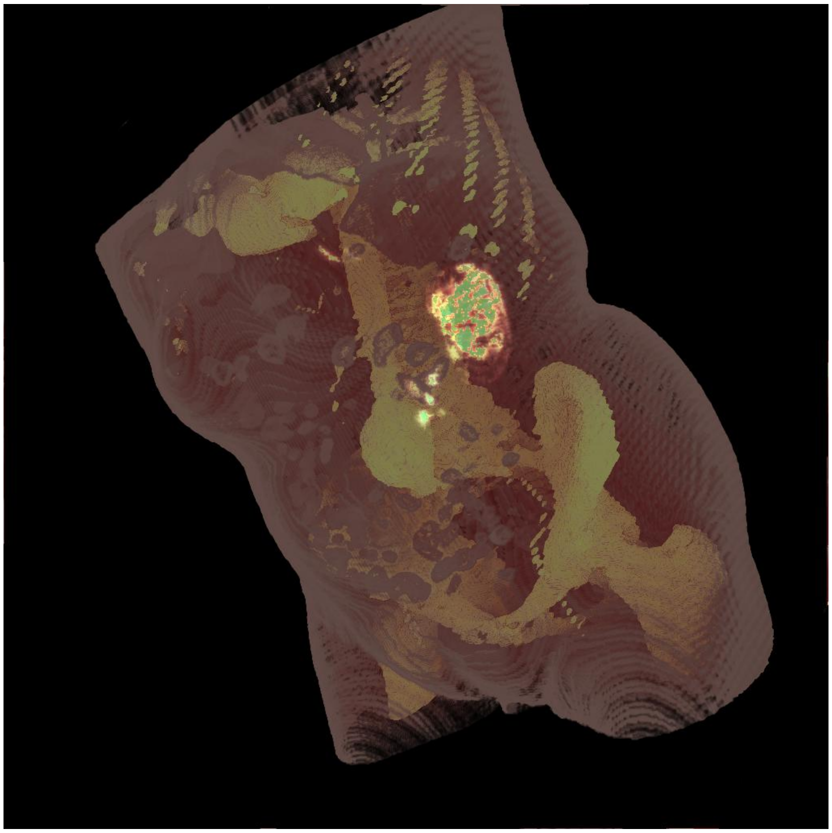
Illustrations



#1. Fixation modeling at VVAM



#2. Method diagram



#3. Gradient based VVAM in ray casting.