Low Cost Interactive Stereoscopic Full Color Direct Volume Visualization of the Visible Human Dataset for Virtual Reality Medical Applications

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Abstract. *Only recently, advanced direct volume visualization techniques have been widely used due to the availability of low cost hardware accelerators; such techniques have a great potential of use for many applications of the virtual reality in medicine. We proposed and implemented a low cost system for interactive and stereoscopic 3D visualization of the full color visible human dataset. Potential use of the proposed system includes anatomical atlases and surgical simulators. A prototype of the proposed system is rendering full color volumes with 256x152x180 in real time (15-20Hz) with stereoscopy.*

Keywords: *Stereoscopy, Virtual Reality in Medicine, Direct Volume Rendering, Visible Human.*

1. Introduction

The majority of the currently available virtual reality applications is based on traditional polygon oriented graphics systems. Recently advanced direct volume rendering techniques such as the ray-casting based on the shear-warp factorization have been implemented in low cost hardware making possible real time and accurate visualization of volumetric data. We believe that these advances will open a broad range of applications in the medical field when we consider the availability of non-invasive high-resolution volumetric data such as the helicoidal computer tomography, functional magnetic ressonance and SPECT imaging.

Potential applications could consider also non-conventional data sources such as the volumetric full color slices made available by the Visible Human Project [Spitzer95], where two corpses (a male one and a female one) were cut in sub-millimeter slices and color photographed in high resolution. Intense research has been done related with the 3D interactive visualization of such datasets, however many approaches consider the use of very expensive supercomputers and high performance parallel computing systems that make impossible the disseminated use of these costly visualization systems.

We proposed and implemented a system for the interactive and stereoscopic direct volume visualization of the visible human color dataset. Our approach is based on the use of low cost hardware platform to make available desktop virtual reality medical applications.

2. The Visible Human Project

In 1989, the National Library of Medicine (NLM) began The Visible Human Project to create a digital atlas of the human anatomy [NLM98]. The digital atlas is based in two datasets: The Visible Man and The Visible Woman. Multimodal 3D medical imaging that includes Xray Computed Tomography and Magnetic Resonance Imaging (MRI) and axial physical cross-sections composes each dataset.

Full color images (RGB) based on photographs of physical sections of both cadavers are also available. To obtain these images the cadavers were embedded in gelatin, frozen and sliced from head to the toe. As each layer was exposed, a color RGB (24Bits) photograph was taken with a resolution of 2048 by 1216 pixels.

The axial anatomical cross-sections images of the Visible Man are at 1mm intervals and coincide with the Xray CT images, resulting in 1871 full color and CT images. The axial anatomical cross-sections images of the Visible Woman are at 0.33mm intervals, resulting in 5.000 anatomical images. Since the availability of such datasets to the international scientific community, to build applications has been a challenge for many research groups.

Tiede et al. [Tiede96] developed a high-resolution anatomical atlas from the Visible Man color dataset based on the framework of Voxel Man Atlas Project. This project is based on Volume Graphics and aims to offer an interactive volumetric color anatomical atlas of the human body.

Lorensen [Lorensen95, 87] proposed a method for visualization of the visible human dataset based on extracting surfaces from the Visible Man Xray CT dataset. The proposed method used surface connectivity and isosurface extraction techniques to create polygonal models of the skin, bone, muscle and bowels, the same author proposed the same approach on the Visible Women dataset using then the color physical cross-sections.

Reinig et al [Reinig98], proposed a framework for real time interactive visualization and touching of the visible human, their method was based on the Marching-Cubes surface extracting algorithm and texture mapping. The images were rendered on a SGI Infinity Reality Onyx.

3. Volume Visualization and Virtual Reality

3.1 Volume Visualization

Volume Visualization is a generic term that describes algorithms and methods for the 3D display of volumetric datasets. The term volumetric graphics or volume rendering often refers to the images created based on the volume space and then displayed as a parallel or perspective projection onto a flat CRT computer screen. The volume space can be generated from many sources that include computer simulation, seismic analysis, computer tomography, magnetic resonance imaging, PET and SPECT imaging.

Particularly, Direct Volume Rendering [Foley90] is a term to designate that set of rendering algorithms that do a direct mapping among voxels and pixels offering accurate image renderings from the volumetric data set. Volume Visualization deals with potentially huge amounts of data, considering for example the full color visible Woman dataset with 2048x1216x5000 voxels we have around 12Gigabytes.

Levoy [Levoy88] proposed the ray-casting algorithm for direct volume rendering of volume data, the main advantage of this method is the high computer complexity related with the tri-linear resampling the RGBA classified voxels during the composition phase.

Cabral [Cabral94] proposed a volume rendering method based on the 3D-texture memory available in high-end graphics superworkstations such as the SGI Onyx RealityEngine. This method took advantage from the compositing features implemented in hardware of the texture memory. The main disadvantage of such implementation is the cost; the authors reported real time for 256^3 volumes.

Lacroute and Levoy [Lacroute94] proposed the enhanced ray casting based on the Shear-Warp factorization of the viewing matrix, where the tri-linear interpolations were reduced in bi-linear interpolations in each slice of the volume.

3.2 Stereoscopic Volume Visualization

The term volume visualization often refers to the images created from volumetric datasets and then displayed as a parallel projection onto a flat CRT screen. Perspective projection is not so often used since it considers the depth in the overall computation of the projections that significant increases the computational cost of the resampling in the volume rendering. Stereoscopic volume visualization adds the additional depth cue of stereopsis that potentially could have many applications on the virtual reality field. When an observer looks at a 3D scene, the horizontal separations of the eye means that the images projected in the back of each eye for any particular point in the scene differ in their horizontal position, this effect is referred to as binocular disparity or binocular parallax [Hodge92].

Time-multiplexed stereoscopic systems present the stereoscopic image pair by alternating right and left eye of an object on a CRT. Current implementations use an alternation rate of around 120Hz (60Hz image rate for the left eye and 60Hz image rate for the right eye).

3.3 The VolumePro Real-Time Ray-Casting Accelerator Board

The Volume-Pro system is the first low-cost real-time direct volume rendering accelerator board for consumer PCs [Pfister99] made available in august 1999. The introduction of this system made a major impact in the developing of real time applications with this visualization technique that could be available before only in very expensive supercomputers or graphics superworkstations such as the SGI Onyx II machines.

The VolumePro implements the ray-casting direct volume rendering method based on the shear-warp factorization of the viewing matrix, which allows parallel slice-by-slice processing. The system incorporates hardware for gradient estimation, classification and Phong illumination. The system renders 500 Million interpolated

Phong illuminated, composited samples per second enabling real-time volume rendering up to 16 million voxels (256^3) at 30 frames per-second.

3.4 Color&Opacity Classification and Bilinear Interpolation

The rendering pipeline implemented in VolumePro assigns RGBA values to interpolated samples as opposed to many volume-rendering methods which usually classify voxels values first and then interpolate RGBA. The system supports 8 and 12 bit scalar voxels and classification is based on full color 24bit RGB tables and 12bit Alpha (opacity) tables. We call these tables RGBA classification tables.

This RGBA classification scheme results in great accuracy for non-linear mappings from data to color and opacity, however direct rendering of volumes that have been pre-classified in RGBA materials such as the full color Visible Human is not possible.

One major advantage of the ray-casting factorization when compared with related ray-casting methods is that a volume is processed in slice-by-slice order and then bi-linear interpolations instead of tri-linear interpolations delivering a significant reduce of the computing complexity. However, when we consider the interpolation index of color tables, color artifacts are introduced resulting on a poor quality image. Some existing quantization algorithms can be used to minimize this problem, but in this case color tables need to be computed for every new image rendering decreasing dramatically the frame rate. In section 4 we propose a volume rendering pipeline to solve these drawbacks.

4. The Proposed System

The proposed system aims to be a low cost PC based platform to support Virtual Reality on medicine. We considered that many of such applications would be related with training and education of clinical procedures in specific small regions of interest in the human body. An important aspect is when we consider surgical simulators that should not restrict the hands and arms movements of the physician.

Considering these issues we based our conceptual model on the “Fish-Tank” model, where a large desktop screen will establish a “portal” to the virtual world. The time-multiplexed stereoscopic and additional haptic devices specific for each application deliver the sense of immersion to the users with minimal body movements restrictions. Groups up to 5 physicians can easily share the same virtual world with a good sense of immersion. The main problem of such approach is that the sense of immersion is completely lost when users move their view out of the computer screen.

4.1 Hardware and Software Platforms

The hardware platform is a Pentium III 600MHz with 128Mytes RAM with PCI and AGP buses. The graphics adapter is a 3Dlabs Oxygen GVX1-AGP board with support to stereoscopy. One PCI bus is used to connect the VolumePro500 board with 128Mbytes RAM. To support stereoscopy we used the StereoGraphics CrystalEyes shutter glasses [Stereo97] with wireless infrared connection, with three shutter glasses. Finally to support time-multiplexed stereoscopy a Sony-UltraScan 1600HS 21” monitor is attached to the system. Figure 01 shows the implemented system.

The software was implemented in C++, using the VLI VolumePro API [Mitsubishi99] on NT, the warping and display was implemented in NT OpenGL, the resampling, segmentation and filtering were implemented in C.

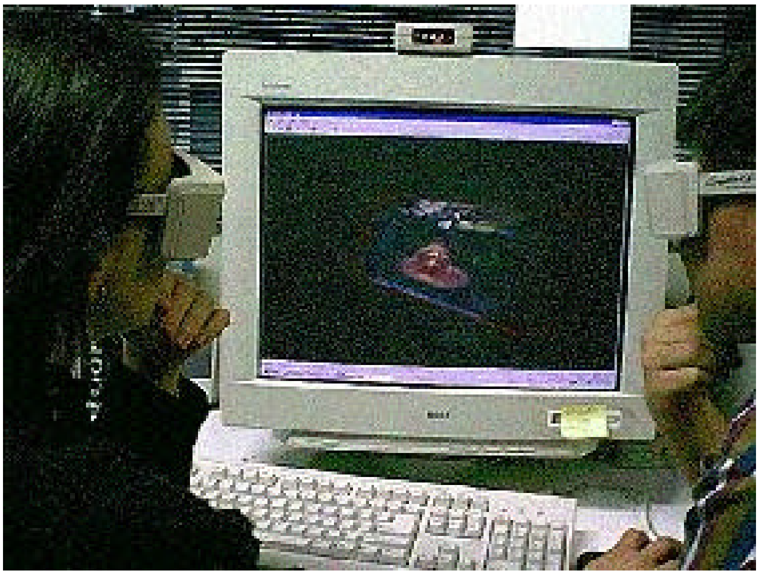

Figure 01 - The Implemented System

4.2 The Visualization Pipeline

The proposed visualization pipeline is showed in Figure 02.

The first step of the visualization pipeline is the resampling of the visible human dataset in order to fit it on the VolumePro memory. We choose 377 slices from the original Visible Man color dataset resulting in a volume with 2048x1216x377 color voxels. The volume was reduced by an 8x8x2 factor resulting in a 256x152x180 voxels.

The resampled volume was segmented to remove the blue gelatine; the segmentation was based on the region growing with tolerance of 20% related to the original RGB seed. A mean 3x3x3 filter was applied to remove additional noise not removed by the segmentation. To classify the voxel opacity we used two methods: gradient modulation and direct opacity mapping.

Since the VolumePro does not have capabilities to render full color pre-classified datasets, our approach was based on the splitting of the original RGB 24 bit volume in three monochromatic 8 bit volumes, respectively the Red, Green and Blue volumes. The VolumePro independently rendered each of these three volumes resulting in monochromatic three stereo pairs. The stereopairs were generated with parallel projection (since VolumePro do not implement yet perspective projection) with the binocular parallax of 7.0.

The three monochromatic stereo pairs were composed on a RGB stereo pair, which is transferred to the GL board for the final image warping and then it is displayed to the user.

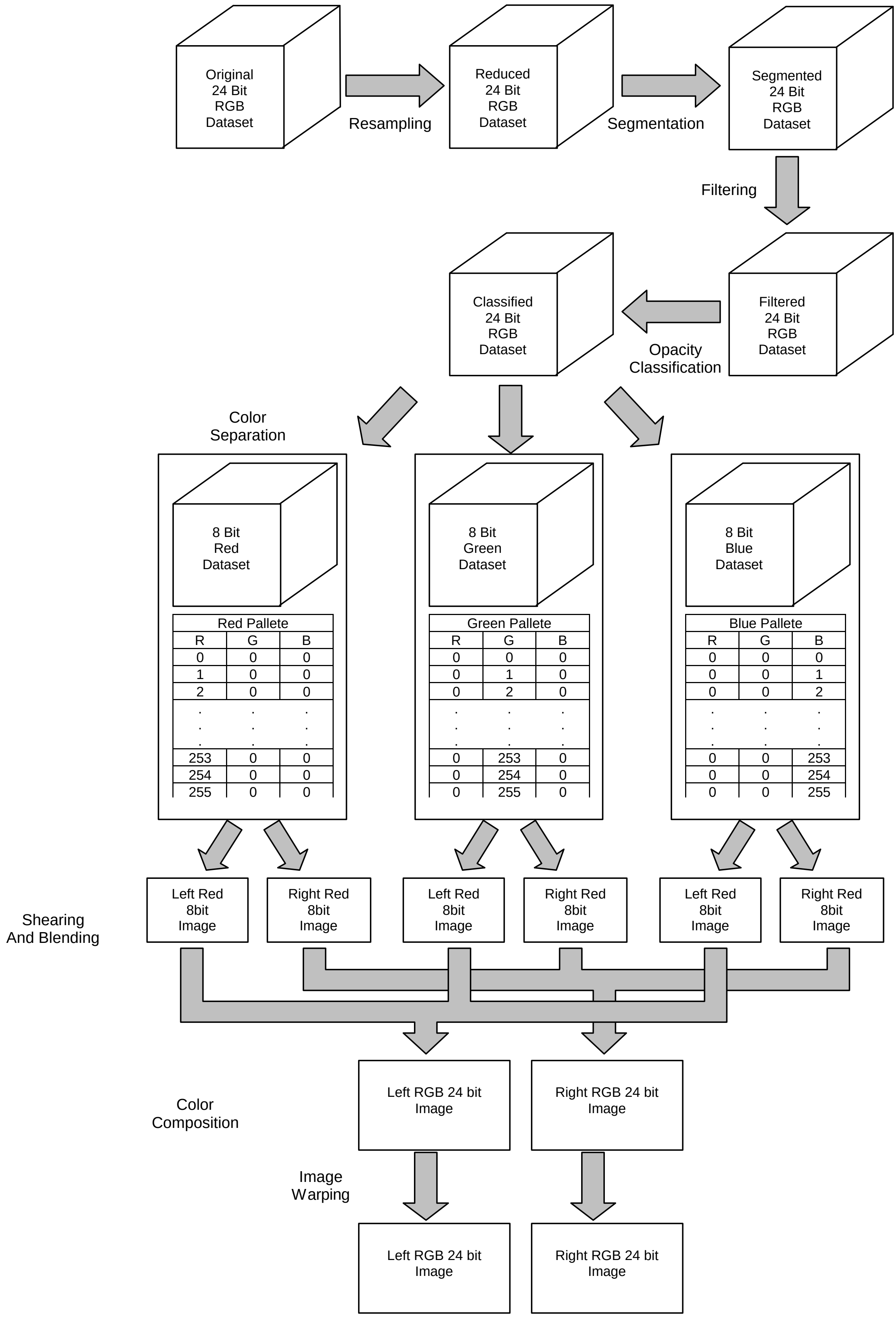

Figure 02 – The Volume Rendering Pipeline

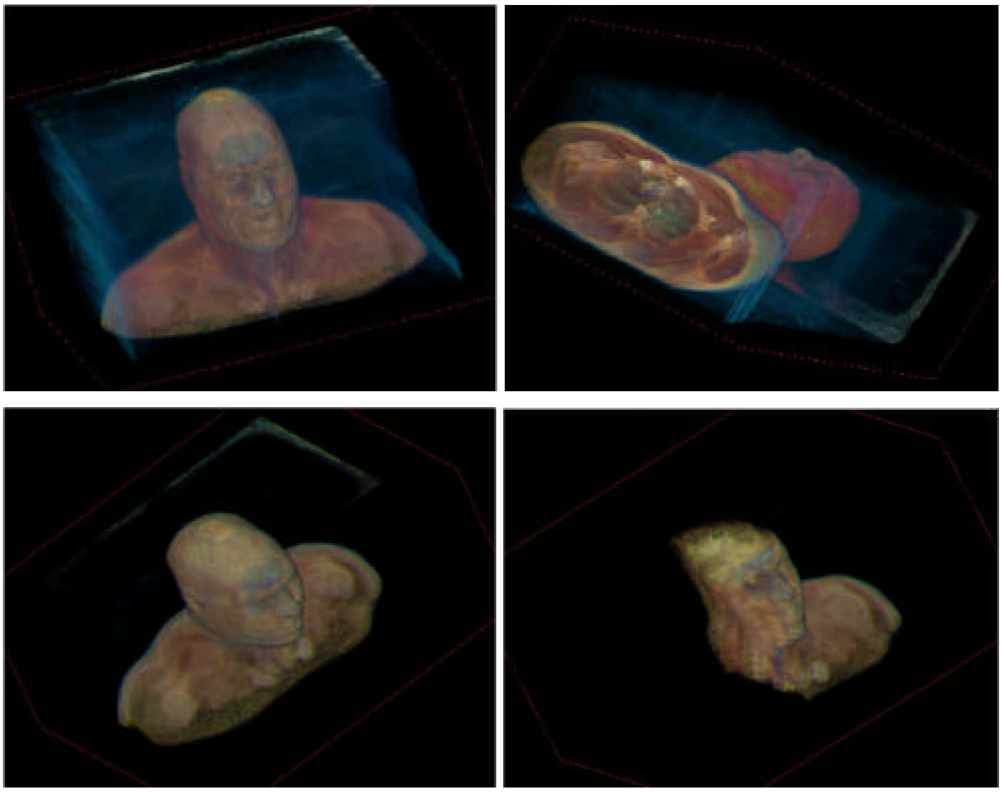

Figure 03 – Rendered Images From the Visible Man Dataset

5. Results

Figure 03 shows some images rendered by our system. Figure 03 (a) and (b) shows two different views of the 256x15x180 dataset without segmentation and filtering, in this case opacity was assigned to maximize the transparency of the gelatin. Figure 03 (c) and (d) shows different views of the 256x152x180 dataset segmented and filtered, Figure 03-(d) shows the dataset with two cutting planes to show the body interior. These images were generated in full screen (1280x1024) with stereoscopy at a frame rate ranging from 15 to 25 Hz.

We tested the system with different users and all of them accepted well the stereoscopy. We consider that this high level of acceptance is based on the fact that the renderings are from semi-transparent objects with a large color dynamic range that can facilitate the binocular disparity even considering that the objects are not projected with perspective projection.

6. Conclusions and Future Work

In this paper we proposed and implemented a low cost 3D stereoscopic full color direct volume visualization system for virtual reality medical applications. Currently the system is rendering full color volumes of 256x152x180 in real time with stereoscopy. The availability of a system like that will open a great potential of applications on medicine that includes anatomical atlases, surgical simulators and related clinical invasive procedures.

Future research directions are related to the use of multi-resolution methods in order to explore the higher resolutions available in these datasets. The proposed implementation does not explored the full memory capacity available in the VolumePro board, that is 128 Mbytes. Future implementations include multiresolution methods to handle volumes up to 256x152x1150 voxels that represent the full cadaver from head to the toe.

Another research direction is the use of multiple VolumePro board in order to build a Surgical CAVE. Our current approach is based on the “Fish-Tank” concept, that despite its advantages in terms of cost and relatively good immersion do not offer full immersive environment. We believe that some applications will demand full immersive systems such as provided by CAVEs. In this case our system could be a cost effective alternative when considering high-end superworkstations.

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