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Real time exploration and management of large medical volumetric datasets on small mobile devices—Evaluation of remote volume rendering approach

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ABSTRACT

In this paper I present the architecture of system that can be used for real time exploration and management of large medical volumetric datasets. The new state of the art solution presented in this paper is an example of visual data management system. System prototype evaluation proved that it is possible to use low-powered (and cheap) up-to-date mobile devices with programmable GPUs as the remote interfaces for exploration of large volumetric medical data. The implementation was done with high-level programming language that enables portability between different hardware models. The lack of lossy compression enables to display high quality medical images visualizations without any simplifications and noises in frequency domain. The prototype of system is capable to remotely render and send to a client (for example cell phone or tablet) rendered data with frequency 30 fps with limited resolution during interaction. One second after the interaction is finished client machine receives full resolution image. The evaluation of the system was performed on volumetric computed tomography angiography image with approximate size 512^3 voxels.

1. Introduction

Computer science is a strongly interdisciplinary branch of knowledge. In informatics, each new scientific and technical achievement that has potential to become valuable commercial product is very quickly deployed into multiple different disciplines of science. Because of this the rapid development in computer science often stimulates the progress of associated disciplines. This influence is especially visible in contemporary medicine and medical systems. Paper (Hachaj & Ogiela, 2013) presents selected applications of computer methods in the field of contemporary medical informatics. The remarkable impact of computer science and telecommunication on medicine is visible in the field of so-called Picture Archiving and Communication Systems (PACS). PACS system is a medical imaging technology that provides economical storage of and convenient access to images from multiple modalities (source machine types) (Mehmet, 2012). The concept of PACS was initiated in 1982, since then PACS have been matured to become an everyday clinical tool for image archiving, communication, display, and review (Huang, 2011). In some cases it is not necessary or not possible for doctor to have direct access to complicated PACS workstations or even face-to-face contact with particular patient (Hachaj & Ogiela, 2013). Report (Kho, Henderson, Dressler, & Kripalani, 2006) suggests that over the past decade, handheld computers (or personal digital assistants – PDAs) have become popular tools among medical trainees and physicians. Many medical students and residents use PDAs for educational purposes or patient care. Most of the studies included described PDA use for patient tracking and documentation, medical textbooks, medication references, and medical calculators as the most useful applications. A PDA can also supply physician with an interface for PACS system however in this case some very serious methodological and technological obstacles have to be overcome. One of the most remarkable problems is real-time visualization of patients' volumetric datasets. Those datasets are mostly products of computed tomography (CT), magnetic resonance (MR), single-photon emission computed tomography (SPECT) or positron emission tomography (PET). Medical 3D visualization is considered real-time if it gives physician capability to interact with visualization by changing the position of observation, declaring clipping planes and modifying transparencies and colors of tissues without noticeable latency. In order to achieve this functionalities scientists and engineers has to incorporate they knowledge about remote rendering, data transmission and mobile devices programming.

This paper proposes system architecture, implementation of prototype and its evaluation that uses small mobile devices (cell phone, tablets, etc.) for real time exploration of large medical datasets. The new state of the art solution presented in this paper

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is an example of visual data management system. This particular type of dataset was chosen because it seems to be one of the most challenging modalities to visualize (because of size and complexity) and also it is commonly used in imaging based diagnosis processes (Ogiela, 2008). In the next sections of this section the state of the art of remote rendering, data transmission and mobile devices programming will be presented. Then I will summarize papers about existing systems with similar capabilities as my proposition. I will also show advantage of my new solution over existing ones.

1.1. Remote rendering

CPU computing in MIMD model (multiple instruction–multiple data) does not allow to obtain sufficient rendering speed for most of real medical volumetric imaging data. Because of that visualizations of that kind are done with algorithm tailored to fit SIMD programming model (single instruction–multiple data). Contemporary mobile devices like cell phones or tablets have its own programmable GPU units that are used for graphic rendering. Modern direct volume rendering algorithms (Hachaj & Ogiela, 2012a, 2012b) enables high performance rendering of volumetric medical datasets on consumers hardware. However those algorithms required big amounts of GPU memory (normally the whole dataset to be visualized should be put into GPU RAM), also they utilize the specialized hardware capabilities like tri-linear interpolation of three-dimensional textures. Those crucial capabilities are inaccessible on low powered mobile GPUs. All of those factors force computer scientist to use different approaches of volumetric data visualization. One of the most common is to use different workstation for image rendering while PDA is used for remote display with touch interface for the user. Multiple approaches of remote rendering were introduced in the past years. First attempts to remote volume rendering techniques were undertaken when there were no dedicated GPU SIMD processors. At the very beginning those types of visualization required employing computer clusters (Hancock & Hubbold, 1997; Renambot, van der Schaafa, Bala, Germansb, & Spoelderb, 2003; Schulze & Lang, 2003; Todd Elvins, 1996). More recently most of common 3D graphic can be rendered on commercial GPU, however there are still cases when remote rendering techniques are utilized: the first case is when amount of data is too large to obtain sufficient frame rate on consumer's GPU and the second case is when we have hardware limitation (for example while rendering on mobile low-power devices). According to Okamoto, Oishi, and Ikeuchi (2011) recent advances in sensing and software technologies enable us to obtain large-scale, yet fine 3D mesh models (nearly 2×10^7 input triangles), however, such large models cannot be displayed interactively on consumer computers because of the performance limitation of the hardware. In paper (Okamoto et al., 2011) authors propose an interactive rendering system for large 3D mesh models, stored on a remote environment through a network of relatively small capacity machines, based on the cloud computing concept. On the server, the 3D models are rendered by the model-based method using a hierarchical data structure with level of detail (LOD). On the client, an arbitrary view is constructed by using a novel image-based method, referred to as the Grid-Lumigraph, which blends colors from sampling images received from the server. The problem of remote visualization of massive geographical data is also described in Zhang et al. (2005). That paper illustrates the ellipsoidal quadtree technique for rapid access multi-scale and multiple level geographical data, integrates the streaming with level-of-detail rendering method for transmitting the data on the network, and implements large-scale terrain surface simplification using M-band wavelet transforms and multiresolution triangulations. Paper (Chityala, Pudipeddi, Arensten, & Hui, 2013) reports usage of a specialized high-end remote visualization system for visualization of dataset that was more than 50 GB in size with more than 6000 2048×2048 slices. In paper (Wua, Gaob, & Chenc, 2009) authors propose an optimized image compositing scheme with linear pipeline and adaptive transport to support efficient image delivery to a remote client. The proposed scheme arranges an arbitrary number of parallel processors within a cluster in a linear order and divides the image into a carefully selected number of segments, which flow through the linear in-cluster pipeline and wide-area networks to the remote client consecutively. In work (Bao, Li, Zhang, & Dong, 2012) authors present a new framework for rendering large-scale forest scenes realistically and quickly that integrates extracting level of detail (LOD) tree models, rendering real-time shadows for large-scale forests, and transmitting forest data for network applications. Experiments show that large-scale forest scenes can be rendered with smooth shadows and in real time.

1.2. Data transmission

The amount of data to be transfer by the net by visualization systems can often be too large to enable efficient sending new list of polygons or rendered frames. Because of that transferring problems are often solved by simplifications of the data model and/or data compression (lossy and lossless). In order to transmit the polygon data to the client efficiently, paper (Zhang et al., 2009) proposes a node-layer data model to manage the 3D scene. A client/server architecture including progressive transmission methods and multi-resolution representations, together with the spatial index, are developed to improve the performance.

The modern network-oriented computer games (as being multimedia network systems) often introduce very interesting communications solutions. Paper (Preda, Villegas, Morán, Lafruit, & Berretty, 2008) describes a framework to develop distributive, multiplayer 3D games. Scalability at the level of content (adaptation and coding) is exploited to achieve the best trade-offs between complexity and quality. Paper (Ohta, Kitahara, Kameda, Ishikawa, & Koyama, 2007) proposes a method to realize a 3D video system that can capture video data from multiple cameras, reconstruct 3D models, transmit 3D video streams via the network (after applying simplifications of captured data), and display them on remote PCs. All processes are done in real time. The teleimmersive environment presented in (Kurillo & Bajcsy, 2013) provides a venue for collaborative work on 3D data such as medical imaging, scientific data and models, archeological datasets, architectural or mechanical designs, remote training. Authors perform network transfer by reducing the size of the 3D video packets and by implementing various network transmission schemes (mostly triangles and colors coding).

Thin wireless mobile devices are unable to handle the complexity of 3D graphics at interactive frame rates. In research work (Boukerche, Pazzi, & Feng, 2008) authors propose efficient end-to-end streaming and rate control protocols. Approach consists of moving the demanding geometry-rendering task to a dedicated remote rendering server that streams the rendering output to a client, leaving only the displaying and certain minor image-based rendering tasks to the local, less powerful mobile hardware.

It can be concluded that proper data exchanging and transmission management might be a key point for obtaining real-time speed of interaction between mobile devices and rendering workstation.

1.3. Mobile devices programming

In case of mobile devices programming (especially when those devices are part of large multimedia systems) system architect has to struggle with limitations of hardware resources. However, when there is access to net many tasks can be computed remotely and