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Visualization Algorithms for Orthopedic Surgery Simulation

A Thesis submitted to the Department of Computer Science, Faculty
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Abstract

During common orthopedic surgery training, students must learn how to perform numerous surgical procedures like fixing fractures which requires training on artificial bones with the usage of surgical tools and implants. These artificial bones have a high cost that depends on the bone's type and quality. Thus the idea of using a computer based simulators for orthopedic surgery training appeared. Simulators will decrease the cost and help students to practice various procedures on a large number of available simulated surgeries in a safe and controlled environment. Also as they are designed dedicatedly for training with specific training goals and high quality visualization of bones, they will have much more to offer than artificial patterns.

Visual representation of the bone is the key element in orthopedic surgery simulation. There were many sensors used to manage this; such as magnetic resonance imaging, computed tomography, and ultra-sound. The past few decades have witnessed an increasing number of new techniques being developed for medical image visualization, which brought profound changes to personal health programs and clinical healthcare delivery. It seeks revealing internal structures hidden beneath skin and muscles, as well as diagnoses and treatment.

Nowadays smart phones have become an essential part of modern human lives and got involved in so many aspects with a wide variety of applications, not excluded from this; health care professionals who can use this device in one of the most prominent aspects of life, health care. Mobile devices became the trend toward information systems and ubiquitous graphical devices and native volume rendering due to their rapid development in the graphics hardware which can be similar to the

PCs. New graphic application programming interfaces (APIs) have been developed as worthy candidates to support the volume rendering core such as; OpenGL ES, Microsoft DirectX 12, AMD's Mantle, and recently Metal API from apple. With the rare existence of medical visualization applications on mobile devices, this study project light on visualization on mobile system and the recent mobile application.

The thesis presents a survey of the recent intelligent techniques and algorithms used for processing medical data visualization. These techniques cover filtering, segmentation, classification and visualization, with a discussion of each process and comparison between the techniques used in each one. The study shows that direct rendering don't need to apply high preprocessing techniques before the visualization step which offer much greater flexibility when compare to indirect rendering which considered as standard for nearly all 3D visualization problems. In addition, indirect rendering cannot detect the information inside the object unlike direct rendering. The study also, presents the recent toolkits and software supporting medical volume visualization.

Based on the literature review and due to the rare existence of free open source medical visualization mobile applications. This study represents mobile application that will help medical students and doctors to show bones processed over in an orthopedic surgery. Experimental results obtained visually by comparing the visualized object from the implemented application to the object obtained from ImageVis3D application. ImageVis3D's development was initiated in 2007 by the NIH/NCRR Center for Integrative Biomedical Computing and additionally supported by the DOE Visualization and Analytics Center for Enabling Technologies at the SCI Institute. The results show that our implementation present better visualized result when compare to

ImageVis3D. The dataset used in the experiment is CT images obtained from Osirix datasets for surgical repair of facial deformity.

Recent in 2015 apple present new graphic application programming interface Metal that can replace OpenGL ES. This study additionally project a light on the performance gained by Metal API over OpenGL ES API and how that can help in the bone visualization. Four dataset used to test the result, namely: Diaphysis, Distal epiphysis, Scapula and knee. The first three datasets used from the laboratory of human anatomy and embryology, University of Brussels (ULB), Belgium, the last one used from Osirix DICOM sample.

List of Publications

1. Yassmin Abdallah, Abdelaziz Abdelhamid, Taha Elarif, Abdel-Badeeh M. Salem, “**Intelligent Techniques in Medical Volume Visualization**”, Elsevier, Procedia Computer Science Journal 65 (2015) 546 – 555.
2. Yassmin Abdallah, Abdelaziz Abdelhamid, Taha Elarif, Abdel-Badeeh M. Salem, “**Comparison Between OpenGL ES and Metal API in Medical Volume Visualisation**”, Proceedings of the 2015 IEEE Seventh International Conference on Intelligent Computing and Information Systems, (ICICIS) Volume 3, pp.160-165, Dec 2015, Cairo, Egypt.

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List of Abbreviations

2D	Two-dimensional.
2DTM	2D texture mapping
3D	Three-dimensional.
3DTM	3D texture mapping
API	Application Programming Interface
CPU	Central processing unit.
CT	Computed Tomography
DSR	Direct Surface Rendering
DVR	Direct Volume Rendering
GPU	Graphics Processing Unit
iOS	iPhone Operating System
ISR	Indirect Surface Rendering
ITK	Insight Segmentation and Registration Toolkit
MIP	Maximum Intensity Projection
MIS	Minimally Invasive Surgery
MPR	Multi-planar Reformation
MRI	Magnetic Resonance Imaging
OASIS	Open Access Series of Imaging Studies
OpenGL ES	Open Graphics Library for Embedded Systems
PET	Positron Emission Tomography
SPECT	Single-photon Emission Computed Tomography
SR	Surface Rendering
VR	Volume Rendering
VTK	Visualization Toolkit

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Chapter 1: Introduction

- **Problem Definition**
- **Thesis Objectives**
- **Contributions**
- **Research Methodology**
- **Thesis Organization**

Chapter 1: Introduction

1.1 Problem Definition

Visual representation of the bone is the key element in orthopedic surgery simulation. There were many sensors used to manage this; such as magnetic resonance imaging, computed tomography, and ultra-sound. The past few decades have witnessed an increasing number of new techniques being developed for medical image visualization, which brought profound changes to personal health programs and clinical healthcare delivery. It seeks revealing internal structures hidden beneath skin and muscles, as well as diagnoses and treatment.

Nowadays smart phones have become an essential part of modern human lives and got involved in so many aspects with a wide variety of applications, not excluded from this; health care professionals who can use this device in one of the most prominent aspects of life, health care. Mobile devices became the trend toward information systems and ubiquitous graphical devices and native volume rendering due to their rapid development in the graphics hardware which can be similar to the PCs.

Despite the rapid development of mobile phones, the existence of medical visualization applications on stores is rare. This study represents a solution for this problem by implements mobile application that helps medical students to show bones processed over in an orthopedic surgery. To achieve this goal, a survey of medical image visualization pipeline illustrate was made to study the techniques and algorithms used in the

visualization field that helped to deliver mobile application with good bone visualization.

In addition a comparison between Metal and OpenGL ES graphics APIs done to project light on the performance gained by Metal API over OpenGL ES API and how that can help in bone visualization.

1.2 Thesis Objectives

The objective of this thesis is to find the most optimal way to visualize bones and presents a mobile application that help students through 1- Performing a review on the visualization pipeline, 2-Implement an iOS application for bone visualization, 3-Compare between recent mobile graphics APIs.

Performing reviews was achieved through listing the techniques and algorithms used in every step of the visualization pipeline and compare between them, while implementing the mobile application achieved through implementing ray casting technique using OpenGL ES on iOS platform, and comparing the new API Metal with OpenGL ES achieved through implementing texture mapping technique on iOS platform and comparing the results.

1.3 Contributions

The thesis presents a study that based on visualization pipeline techniques (Data acquisition, filtering, segmentation, classification, visualization) illustrate each step in the pipeline with a clarification and comparison of each technique used in the step.

This study also represent proposed mobile system for orthopedic surgery that visualize the medical data using RayCasting technique and represent the result on mobile screen.

In comparison to the other techniques, **RayCasting** is widely accepted as the best quality volume rendering technique.

The thesis also represents a comparison between the recent API used in mobile to compare the rendering time it's takes to render medical object data. The comparison made between Metal and OpenGL ES API and the results shows that Metal present faster rendering time (rendering time for one 3D object was 1.76 sec compared to 2.18 sec obtained from OpenGL ES)

1.4 Research Methodology

To achieve the goal of this thesis firstly, a review on the visualization pipeline presents. Visualization pipeline [1,2,3] presents in Figure 1.1, the pipeline contains five processes used to preform volume visualization on medical image. The first process is the acquisition of dataset, after that dataset filtered for enhancing the quality of the medical image, then segmentation step done to locate objects of interest for the medical image. After the possible selection of a sub-range of the voxels, the normal of the voxels are computed. For the last step before the actual rendering, the voxels are classified. Finally, the voxels are visualized.

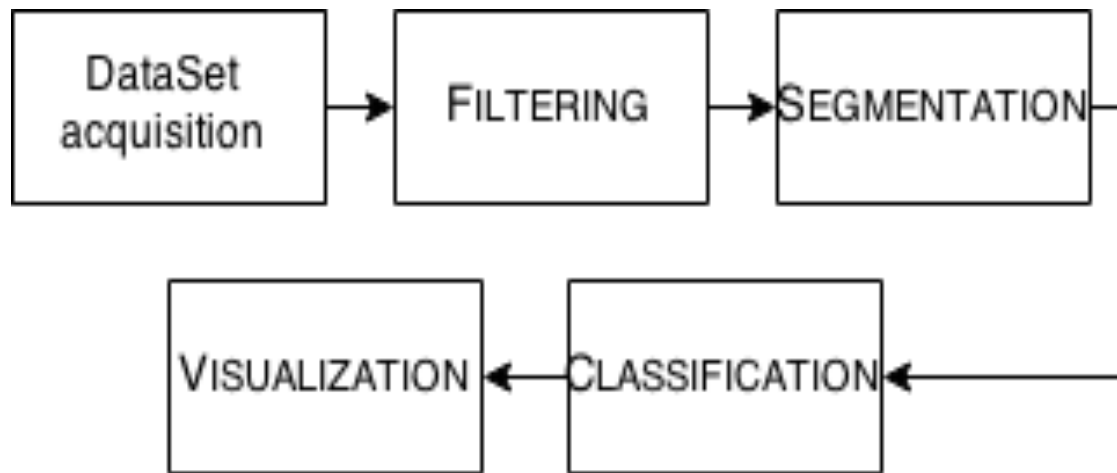


Figure 1.1: visualization pipeline

Based on the result obtained from this survey and due to the rare existence of medical visualization mobile applications, this study represents mobile application, that implement direct rendering ray casting technique, that will help medical students and doctors to show bones processed over in an orthopedic surgery.

The implementation of the mobile application done based on The Visualization Toolkit (VTK). The Visualization Toolkit (VTK) is a freely available software system for 3D computer graphics, image processing and visualization.

The comparison between graphic application programming interfaces presents by compare OpenGL ES with the recent API from apple Metal. The comparison done by implemented texture mapping technique with both APIs. The implementation uses native iOS application.