

# IEEE Recommended Practice for Three-Dimensional (3D) Medical Modeling

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**IEEE Computer Society**

Approved 16 February 2015

**IEEE-SA Standards Board**

**Abstract:** The generation and practical use of medical three-dimensional (3D) modeling for diagnostics and therapeutic applications is described in this standard. Volume rendering and surface rendering techniques for 3D reconstruction from two-dimensional (2D) medical images and a texturing method of 3D medical data for realistic visualization are included.

**Keywords:** IEEE 3333.2.1™, material properties, medical 3D decimation, medical 3D format, medical 3D reconstruction, medical 3D segmentation, standard for medical 3D, texture mapping.

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## Introduction

This introduction is not part of IEEE Std 3333.2.1™-2015, IEEE Recommended Practice for Three-Dimensional (3D) Medical Modeling.

Medical images from hospitals consist of a 2D dataset and provide human body information as a slice. The human body has morphological structures in 3D space. To recognize real human organs, the body should be reconstructed using 2D slices to obtain its precise position and shape. In real clinical situations, doctors expend a great deal of time and effort to learn this reconstruction process. With medical 3D data, we will obtain more information about the human body, as well as more objective data from the simulation, which may contribute to more successful treatment and surgery plans.

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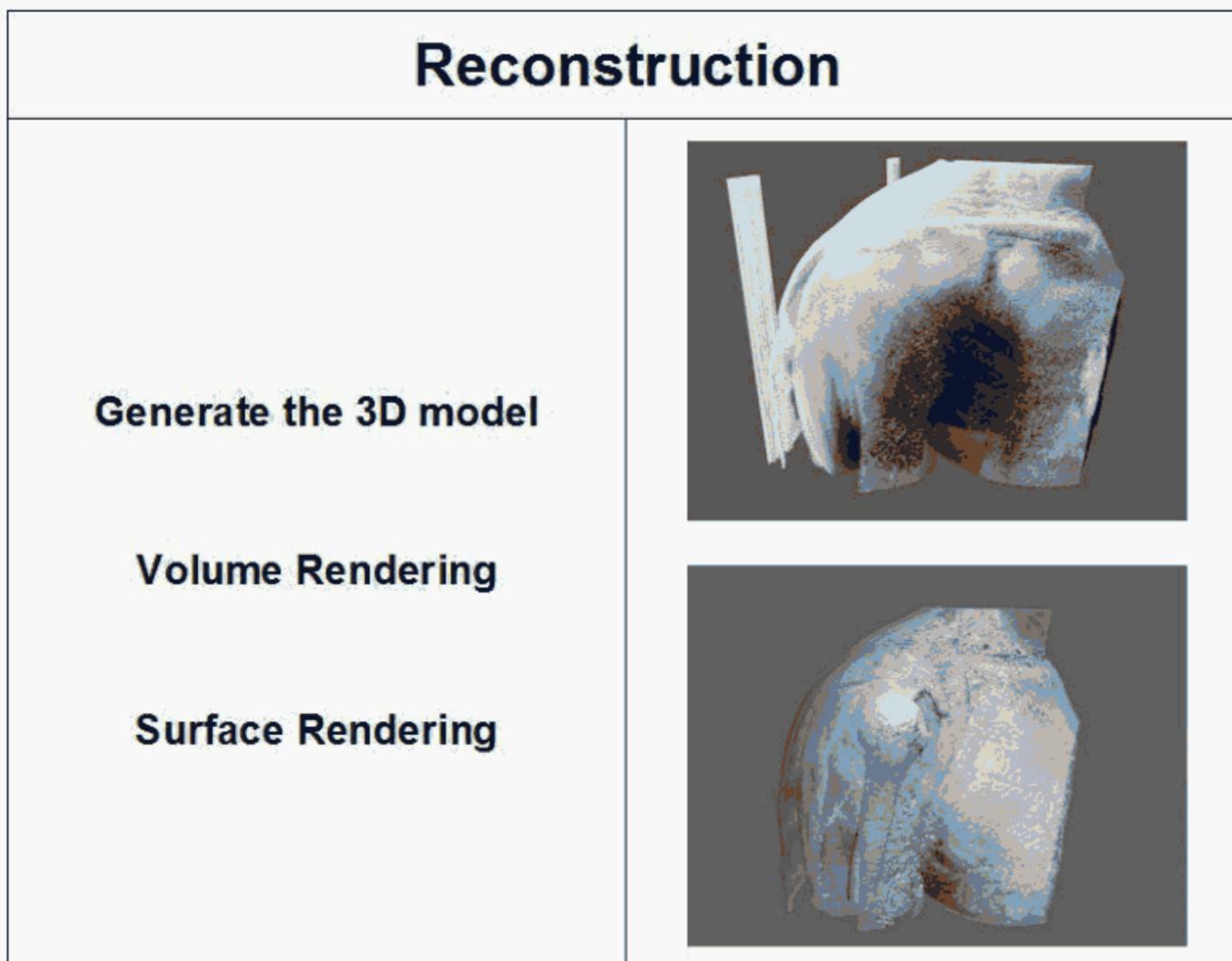
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## 1. Overview

### 1.1 Background

Medical images from hospitals consist of a two-dimensional (2D) dataset and provide human body information as a slice, but the human body has three-dimensional (3D) morphology. If we should simulate this 3D morphology, we might be able to obtain more information about the body as well as contribute in the clinical environment to both treatment and surgical outcomes. Our objective is to generate 3D medical data from 2D images. Although doctors expend a great deal of time and effort in this process, the resultant 3D data is different in each institute. This protocol, therefore, provides standard, easy, and accurate 3D data for clinical fields and even for industrial markets.

A standardized file with 3D medical data, considering each data character from a different place, will yield steady quality visualization. Therefore, this standard suggests standardized data including 3D processing techniques. A more realistic 3D model and a basic model are shown in Figure 1.

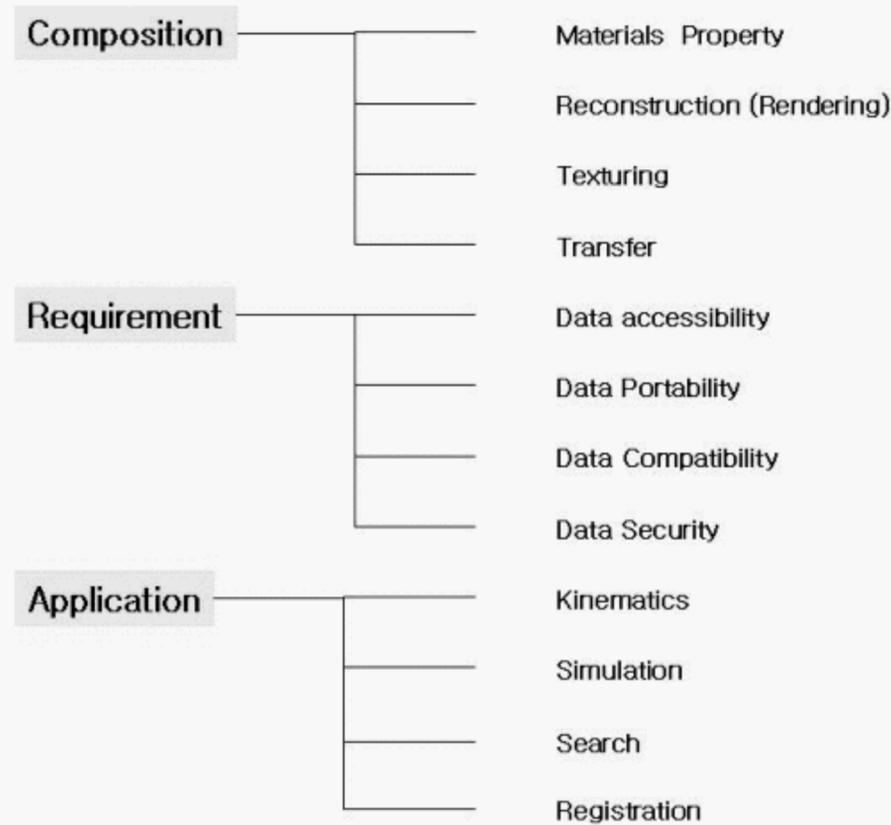


**Figure 1—Reconstruction of 3D modeling from medical data generated by a volume- and surface-rendering process**

## 1.2 Scope

This standard includes volume- and surface-rendering techniques for 3D reconstruction from 2D medical images. Also, it contains a texturing method of 3D medical data for realistic visualization.

Standardization related to medical services includes medical equipment utilizing 2D images, 3D medical data, and contents for diagnosis and treatment. Standardization of medial contents, software, and hardware will enhance safety, economy, and quality of 3D medical services. (see Figure 2).



**Figure 2—Whole framework configuration**

### 1.3 Purpose

Medical images from hospitals consist of a 2D dataset, providing information from the human body as sectioned slices. The human body has morphological structure in 3D space. Therefore, to recognize human organs, the 3D reconstruction process is necessary to be reformed using 2D slices. After this, the precise position and shape of organs can be identified.

Medical 3D volume imaging is based on unprocessed 3D medical data that contains a variety of medical information. It determines guidelines, standards of medical 3D technology, and the 3D volume image's safety and quality. This standard describes the generation and practical use of medical 3D modeling for diagnostic and therapeutic applications.

## 2. Definitions, abbreviations, and acronyms

### 2.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>1</sup>

**decimation:** A reduction in the number of triangle meshes for polygonal simplification.

**polygon:** Segments surrounded by the vertex and line of three or more (triangular, square, pentagonal) depends on the number of segments or objects that are connected to form a polygon.

<sup>1</sup>*IEEE Standards Dictionary Online* subscription is available at:  
[http://www.ieee.org/portal/innovate/products/standard/standards\\_dictionary.html](http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html).

**reconstruction:** Methods to construct images of a medical information file.

**rendering:** Generating an image from a model by means of computer programs.

**segmentation:** By analyzing the original image, the image is extracted with the nature and characteristics of a structure.

**STL:** File format used to represent three-dimensional (3D) computer-aided design (CAD) models in stereolithography and other solid free-form fabrication technologies.

**surface:** Three-dimensional (3D) representation of the shape by line segment.

**texture mapping:** Applied (mapped) texture of material property at the surface of a shape or polygon.

**volume:** Three-dimensional (3D) visualization technique for the interior of the object model; used to display a 2D projection of a 3D discretely sampled dataset.

**volume pixel (voxel):** A value on a regular grid (x,y,z) in 3D space such as pixels (x,y) in a 2D plane.

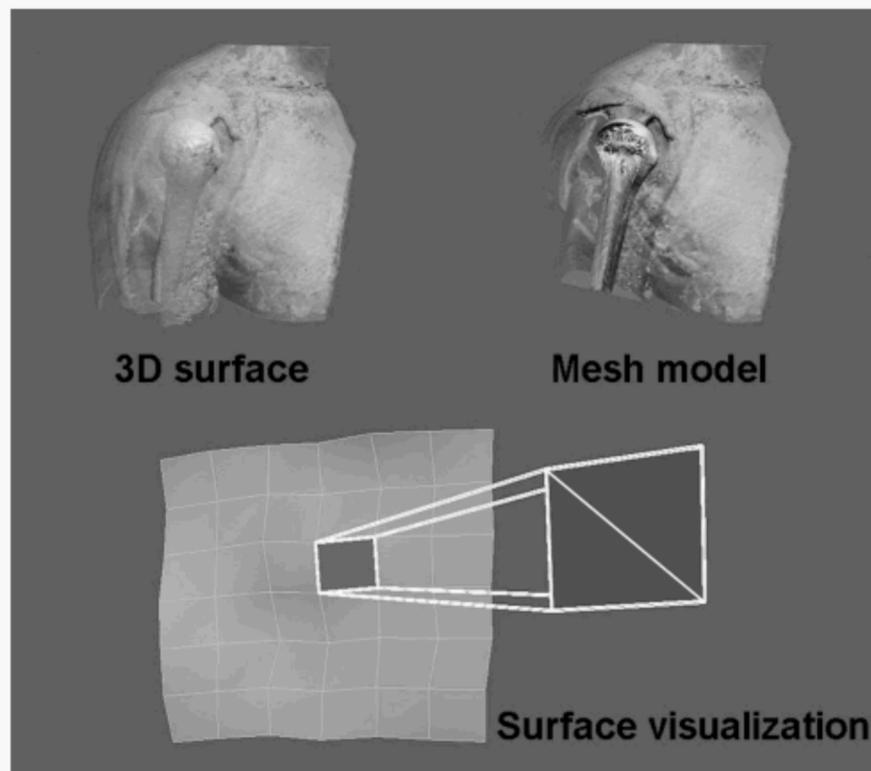
## 2.2 Abbreviations and acronyms

2D	two-dimensional
3D	three-dimensional
CAD	computer-aided design
CT	computed tomograph
MIP	maximum-intensity projection
MRI	magnetic resonance image
ROI	region of interest
STL	Standard Tessellation Language
STL Format	a file format to the stereolithography computer-aided design (CAD) software created by 3D systems
voxel	volume pixel

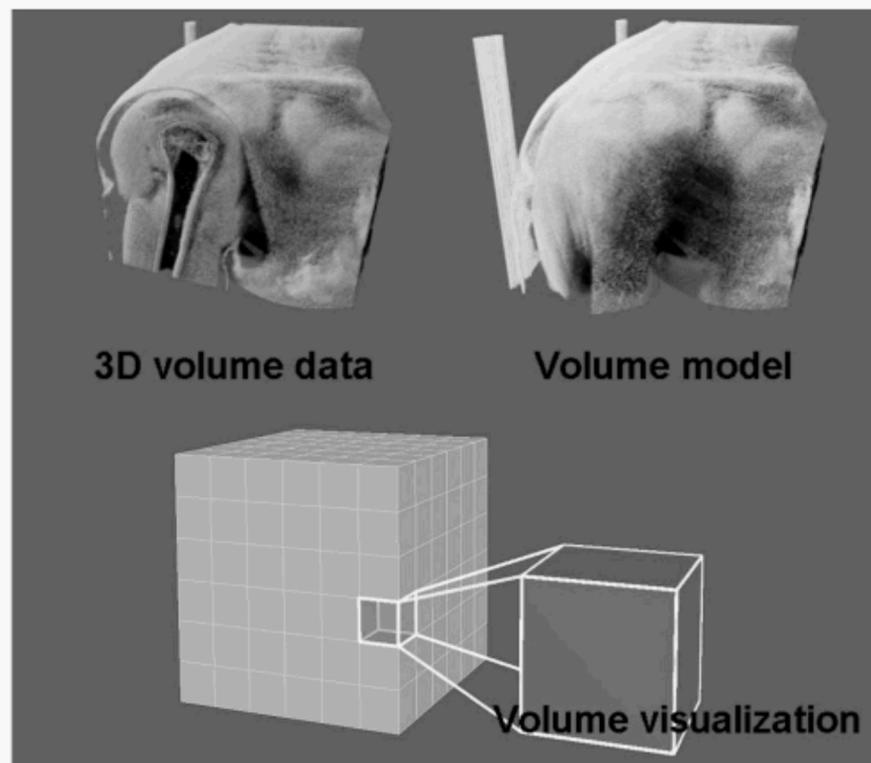
## 3. Medical 3D modeling information

### 3.1 Overview of 3D modeling

A 3D model with laminating 2D slices shall be reformed in two ways, depending on the region of interest (ROI): surface rendering, which shows only surface, and volume rendering, which shows inside data. The suggested standard file format supports the two rendering methods (see Figure 3).



(a)



(b)

**Figure 3—Rendering methods: (a) surface rendering (outer surface visualization)  
(b) volume rendering (inner and outer visualization)**

## **3.2 Modeling architecture**

### **3.2.1 Medical image acquisition**

#### **3.2.1.1 Background**

An important ingredient in further improving 3D video-processing technologies is the incorporation of better models of 3D perception. Among these, saliency detection, or the automated discovery of points of high visual interest, conspicuity, or task relevance, is a challenging problem.

#### **3.2.1.2 General requirement**

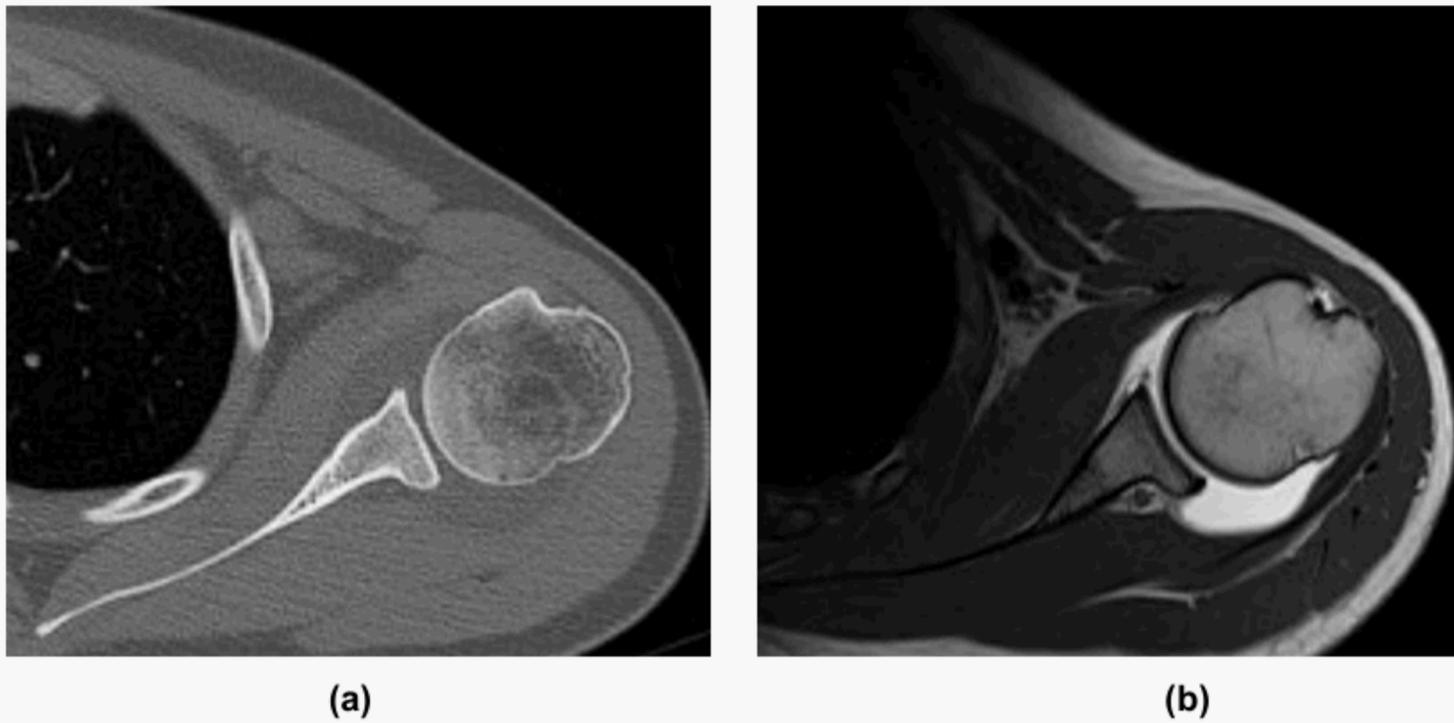
In the medical field, the most important problems are treatment planning and virtual practice from advanced imaging modalities. These problems should be solved by employing various methods using a 3D model of the patient, which will improve diagnostic accuracy and allow for the simulation of medical procedures using a controller.

Accurate 3D models shall be obtained by 3D reconstruction of serial sectional images of the structures that are derived from computed tomographs (CTs) and magnetic resonance images (MRIs).

#### **3.2.1.3 Acquisition procedure**

To make 3D patient models, sequential 2D images are necessary and should be acquired from CTs, MRIs, and an optical microscope. Generally, 2D patient images should be acquired from a CT or MRI scanning of the patients' body by intervals of a few millimeters.

Each image has its own strengths and weaknesses according to what has been observed. In the case of CT, bones will be clearly identified, therefore bone- or joint-related diseases will be effectively shown. In the case of MR, cartilage, muscle, and nerves will be clearly shown as well as the bone, therefore MR is shown to be more effective (see Figure 4).

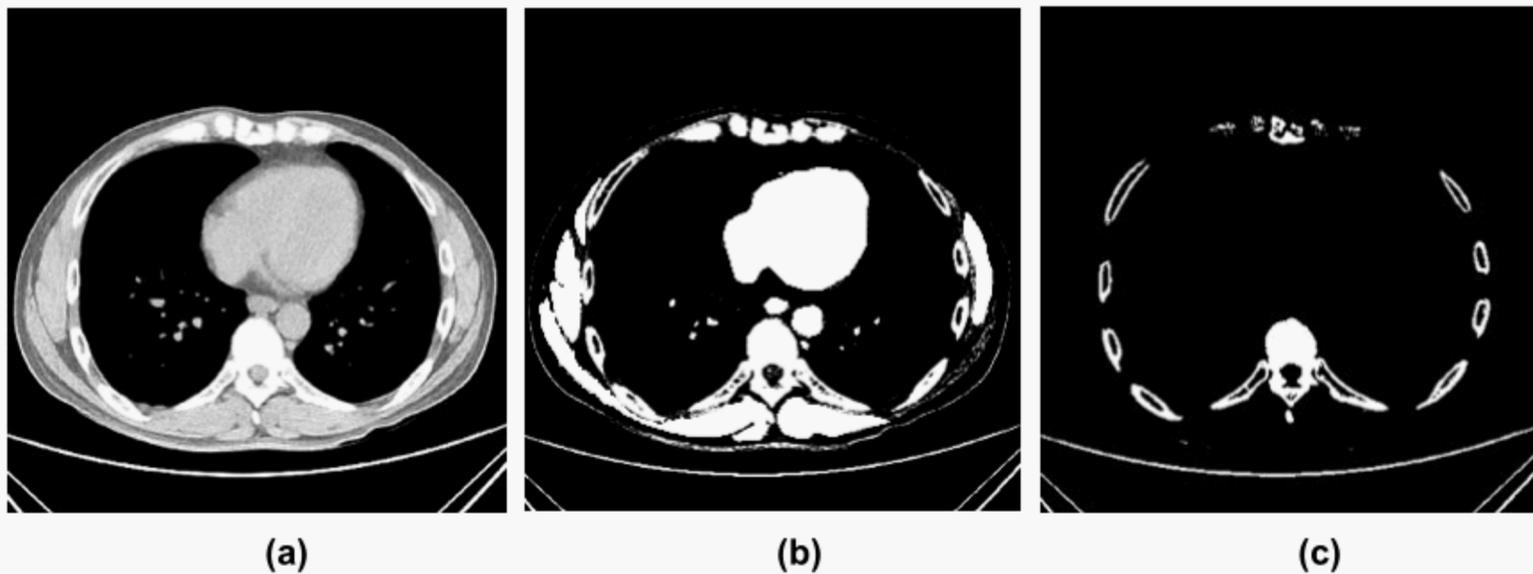


**Figure 4—Comparison of (a) CT and (b) MR images of the thoracic region. On the CT image, bones and air passages are clearly identified. On the MR image, the borders of muscles and organs are more clearly identified than in the CT image.**

### 3.2.2 Medical image segmentation

Medical image segmentation should be done using medical 3D modeling. Image segmentation divides an image into homogeneous structures of the same region or similar nature by defining the boundaries of transitional edges.

Several segmentation methods have been utilized, including edge detection, region growing, thresholding, morphological operation, watershed segmentation, edit mask, and manual operation (see Figure 5).



**Figure 5—Image process to segmentation: (a) original image, (b) edge detection, and (c) image morphology.**

### 3.2.3 Temporal characteristics of 3D contents

A medical 3D model using the phase information of segmentation and feature will be able to reconstruct a patient's body. Medical 3D reconstruction shall be completed with surface- and volume-rendering data.

## 4. Segmentation

### 4.1 Overview of segmentation

Segmentation in medical imaging is generally considered a difficult problem, mainly because of the sheer size of the datasets coupled with the complexity and variability of the anatomic organs. The situation is worsened by the shortcomings of imaging modalities, such as sampling artifacts, noise, low contrast, etc., that may cause the boundaries of anatomical structures to be indistinct and disconnected. Thus, the main challenge of segmentation algorithms is to accurately extract the boundary of the organ or ROI and separate it from the rest of the dataset.

### 4.2 Segmentation methods

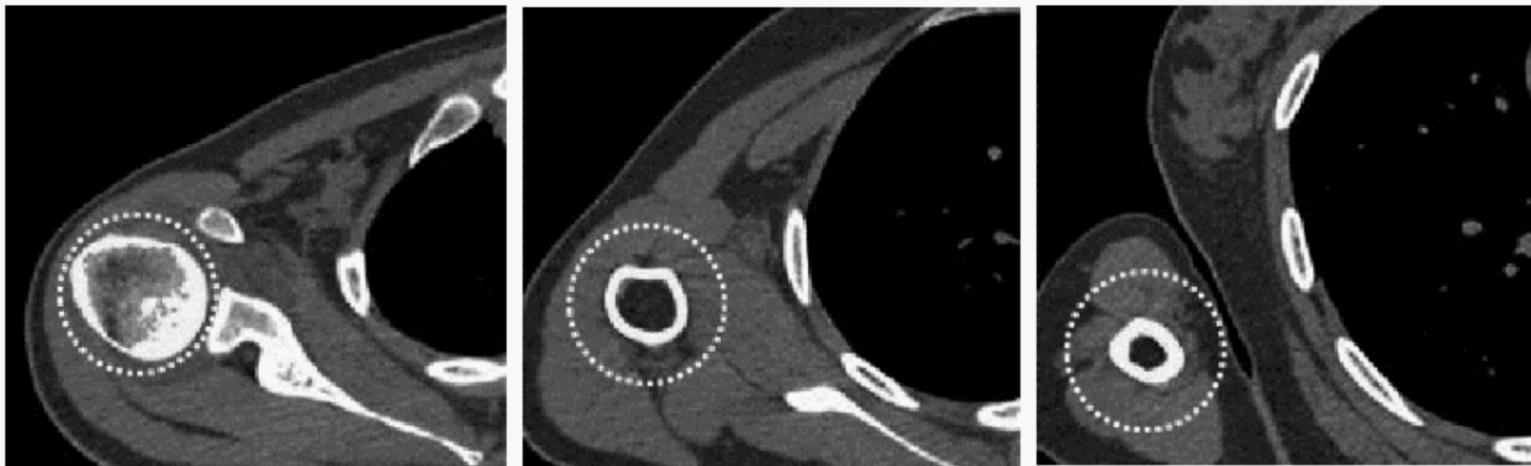
Numerous segmentation algorithms are found in the literature. Due to the nature of the problem of segmentation, most of these algorithms are specific to a particular problem and thus have little significance for most other problems.

This standard will try to cover all the algorithms that have a generalized scope and that are the basis of most current segmentation techniques. In addition, we will concentrate only on 3D volumes and thus present each algorithm with respect to its application on 3D volumes.

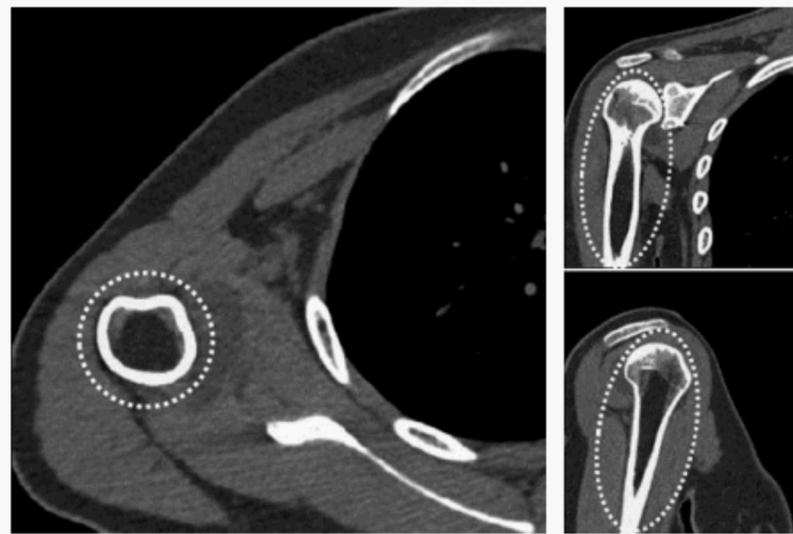
To make 3D models from 2D images, it was necessary to segment the area of interest in the 2D image. 3D models were made by stacking serial 2D images, therefore segmentation was also done consecutively. Generally, segmentation was done on horizontal images, but in some cases, segmentation was done on coronal or sagittal images that were made by stacking horizontal images and then cutting in the coronal or sagittal directions (see Figure 6).

In the medical imaging field, a variety of algorithms for the automation of segmentation have been developed [B1], [B3], [B4], [B5]. However, some anatomical structures cannot be segmented automatically, such as detailed muscles, because the borders of neighboring structures were not clearly identified on 2D images.

Segmentation could be done efficiently using commercial software that handles medical images [B6], [B10]. These software packages have many functions, including semiautomatic segmentation, when optimally used.



(a)



(b)

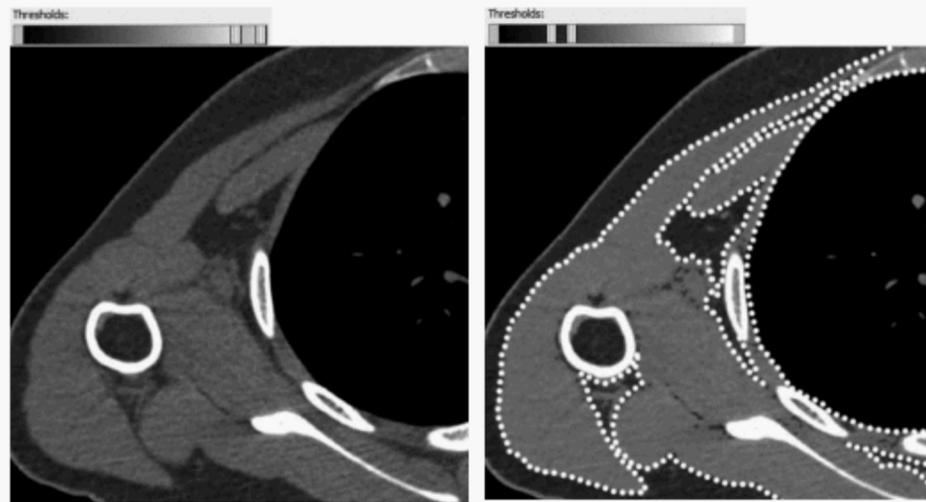
(c)

**Figure 6—Segmentation of the humerus on a CT image:**  
**(a) The humerus could be serially segmented on horizontal images.**  
**(b) Axial images. (c) Coronal images and sagittal images.**

#### 4.2.1 Thresholding

Thresholding approaches segment scalar images by creating a binary partitioning of the image intensities. A thresholding procedure attempts to determine an intensity value, called the threshold, that separates the desired classes. The segmentation is then achieved by grouping all pixels with intensity greater than the threshold into one class and all other pixels into another class (see Figure 7).

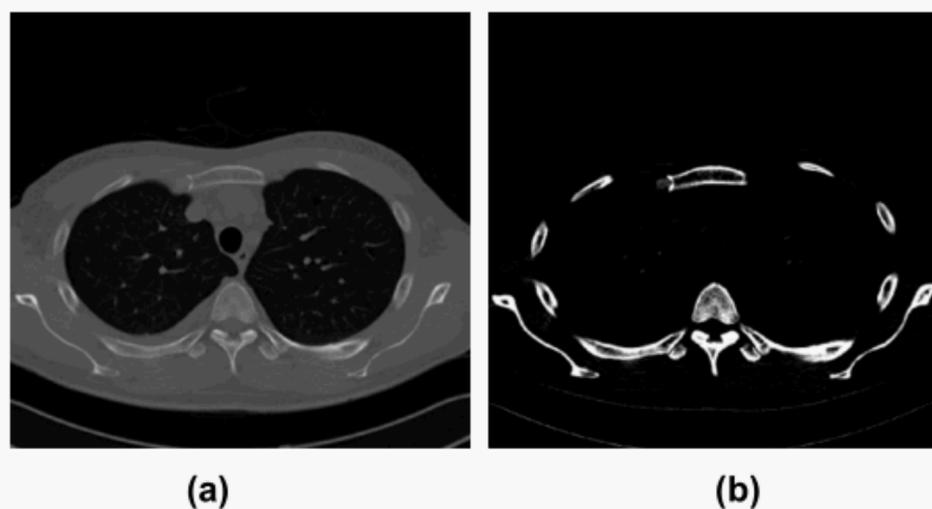
Thresholding is often used as an initial step in a sequence of image-processing operations. Its main limitations are that, in its simplest form, only two classes are generated, and it cannot be applied to multi-channel images. In addition, thresholding typically does not take into account the spatial characteristics of an image, which causes it to be sensitive to the noise and intensity inhomogeneities that will occur in MRIs. Both these artifacts essentially corrupt the histogram of the image, making separation more difficult. For these reasons, variations on classical thresholding have been proposed for medical image segmentation that incorporates information based on local intensities and connectivity.



**Figure 7—Thresholding process**

#### 4.2.2 Region growing

The region growing segmentation method examines neighboring pixels of initial seed points and determines whether the pixel neighbors should be added to this region. In this way, segmentation shall be done by adjusting the set seed point and pixel neighbors. Selecting the desired regions and growing them is a simple technique but it should improve the results of segmentation (see Figure 8).



**Figure 8—Segmentation by region-growing method: (a) before and (b) after.**

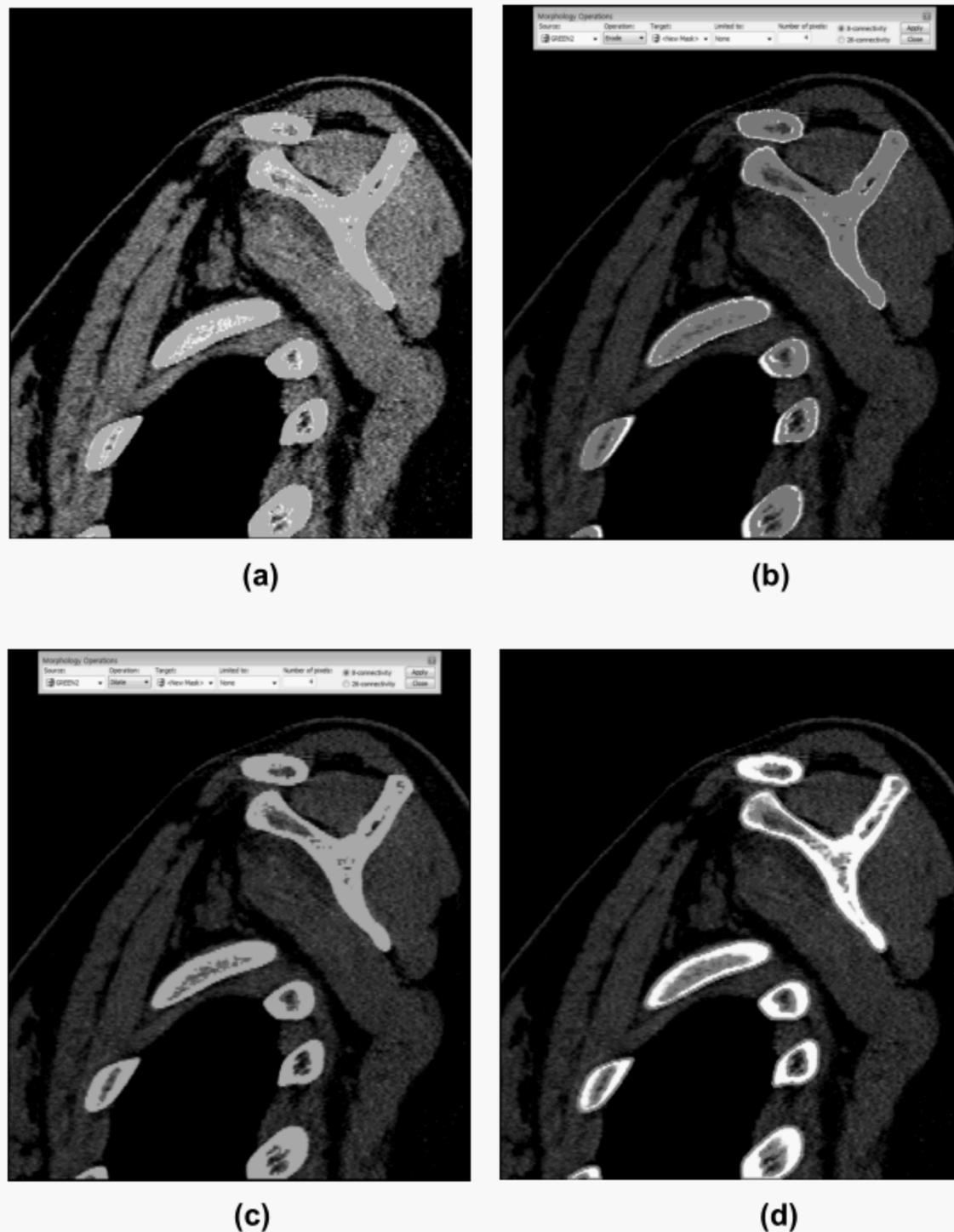
#### 4.2.3 Live-wire/manual operation

The live-wire algorithm traces a desired contour by moving a pointer by user-steered segmentation for 2D images using the gradient information of the volume data to correct the movements according to the underlying material transitions.

#### 4.2.4 Morphological operations

Mathematical morphology uses set transformations for image analysis. This image process transforms specific types of objects in an image using a set of relationships: move, mirror, complement of set, and difference of sets. Typical mathematical morphological methods use Erode and Dilate operations.

Erode takes pixels from the edges. Erode followed by a “region grow” should separate parts and Dilate will add pixels from the edges, which should be used to restore the effect of the erosion (see Figure 9).



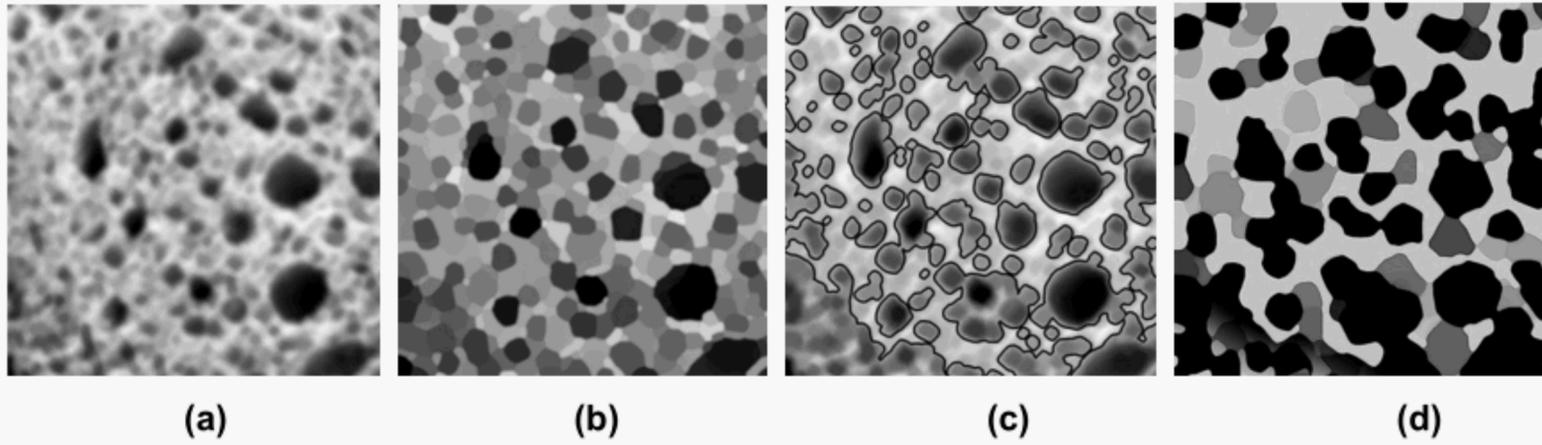
**Figure 9—Apply morphological operation segmentation:  
(a) original image, (b) erosion, (c) dilation, and (d) final result.**

#### 4.2.5 Watershed segmentation

The watershed is a classical algorithm used for segmentation, that is, for separating different objects in an image, but it is also a useful technique in medical fields.

Starting from user-defined markers, the watershed algorithm treats pixel values as a local topography (elevation). The algorithm floods basins from the markers until the basins attributed to different markers meet on watershed lines. In many cases, markers are chosen as local minima of the image, from which basins are flooded (see Figure 10).

The watershed algorithm determines the catchment basins that are separated by the ridge lines.

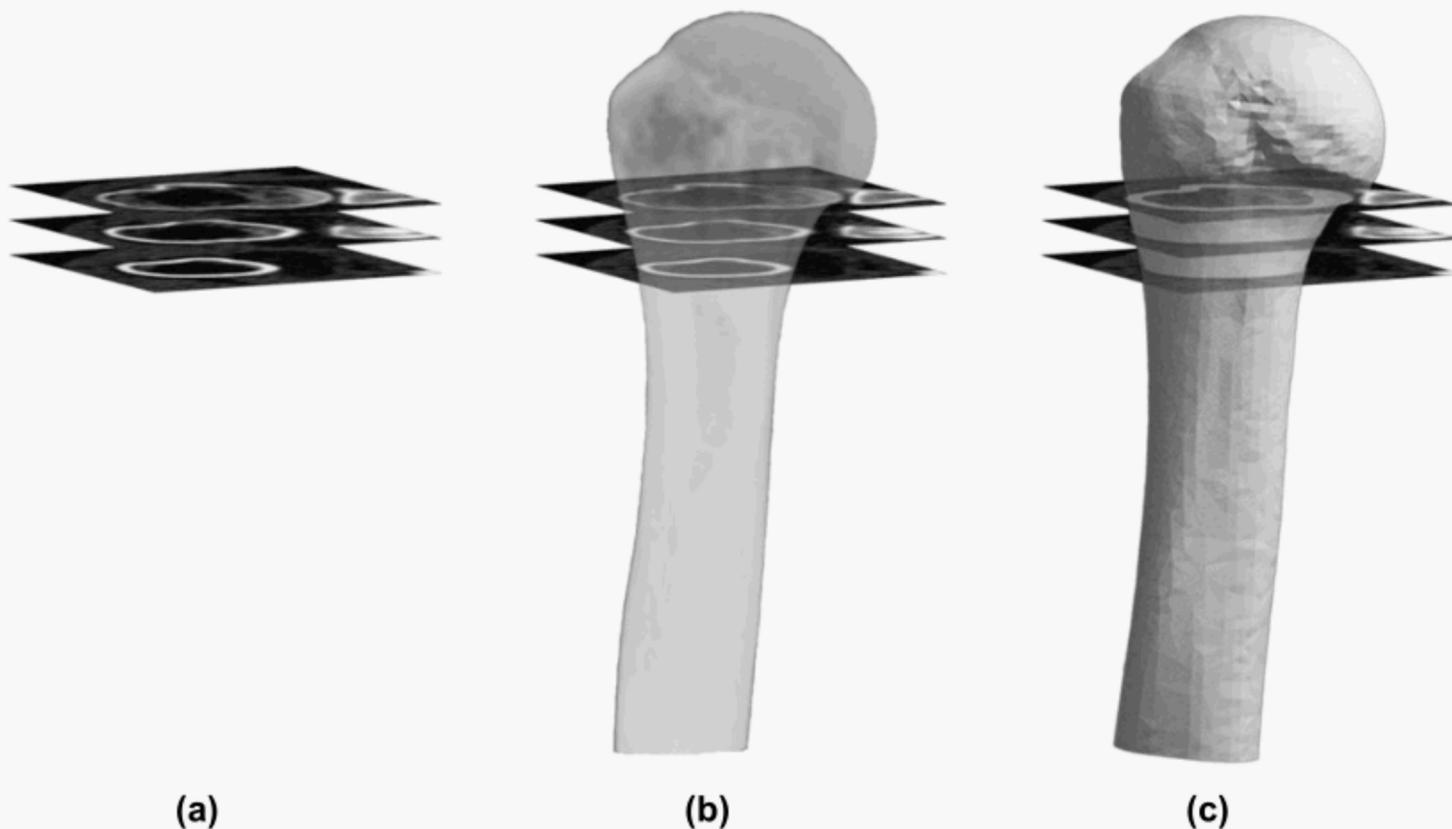


**Figure 10—Watershed segmentation process:**  
(a) input, (b) dams, (c) dams until 150, and (d) catchment basins

## 5. Reconstruction

### 5.1 Overview of reconstruction

3D models shall be made by stacking serial segmented images. Volume 3D models were made as follows: the segmented images were simultaneously expanded onto the next images to build several small volume models, referred to as volume reconstruction. Finally, all volume models were combined. From the combined volume models, a surface model was extracted, which was referred to as the surface reconstruction. Generally, the volume and surface reconstructions were simultaneously performed on reconstruction software. The resulting surface model consisted of the original stacked outlines and numerous triangular surfaces between the outlines (see Figure 11).



**Figure 11—Procedure of 3D reconstruction: (a) segmented images, (b) several volume 3D models, (c) surface 3D model extracted from volume 3D model.**

Volume and surface 3D models have different file formats according to the software used, so exchanging data and using other software was difficult. Therefore, the surface model, comprised of stacked outlines and polygons between outlines, should be converted in the drawing, exchange format (DXF), or other popular formats. In some cases, the 3D models will be converted to a non-uniform rational B-spline (NURBS) surface.

3D reconstruction procedures shall be done on medical-oriented software, commercial 3D reconstruction software, researching segmentation software, or via an in-house program (see Figure 12). In some cases, popular software may be used for surface reconstruction independent of computer programmers [B6], [B12].



**Figure 12—3D model of a humerus. After volume reconstruction, the surface was extracted on commercial reconstruction software.**

## 5.2 Surface rendering

### 5.2.1 Background

Surface 3D reconstruction is performed by means of triangulation of a segmented 3D area. The number of triangles determines the quality of the reconstruction. A surface 3D model shall be made in the Standard Tessellation Language (STL) Format to configure the 3D surface reconstruction.

### 5.2.2 STL Format

STL Format a stereolithography computer-aided design (CAD) software is widely used for rapid prototyping and computer-aided manufacturing. STL files describe only the surface geometry of a 3D object without any representation of color, texture, or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common because they are more compact.

The file begins with a solid record (which shall include a name for the object) and ends with an end solid record. Each triangle begins with a facet record and ends with an end facet record. The normal vector, if

given, is included as part of the facet record, and is identified by the normal keyword. The normal vector should have unit length. The three vertices of the triangle are delimited by outer-loop and end-loop records. Each vertex is described on a vertex record that lists its (X,Y,Z) coordinates (see Figure 13).

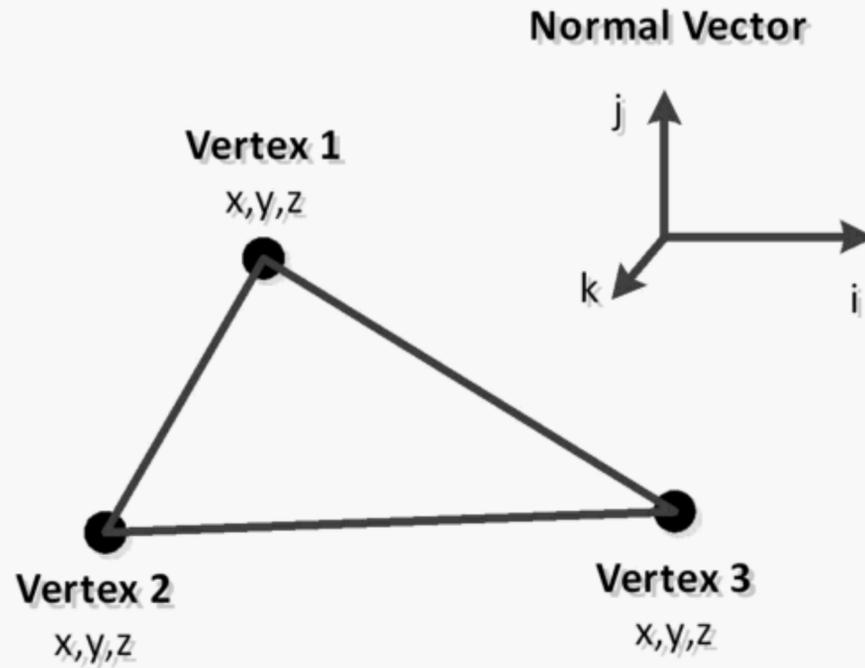


Figure 13—STL format diagram

### 5.2.3 Polygon decimation

Depending on the scan machine, purpose, or situation, surface models have different polygon amounts. Therefore, polygon reduction is necessary. However, during heavy reduction, small anatomical feature points will be removed. To avoid this problem, reduction has to be done below the preservation of anatomical features (see Figure 14).

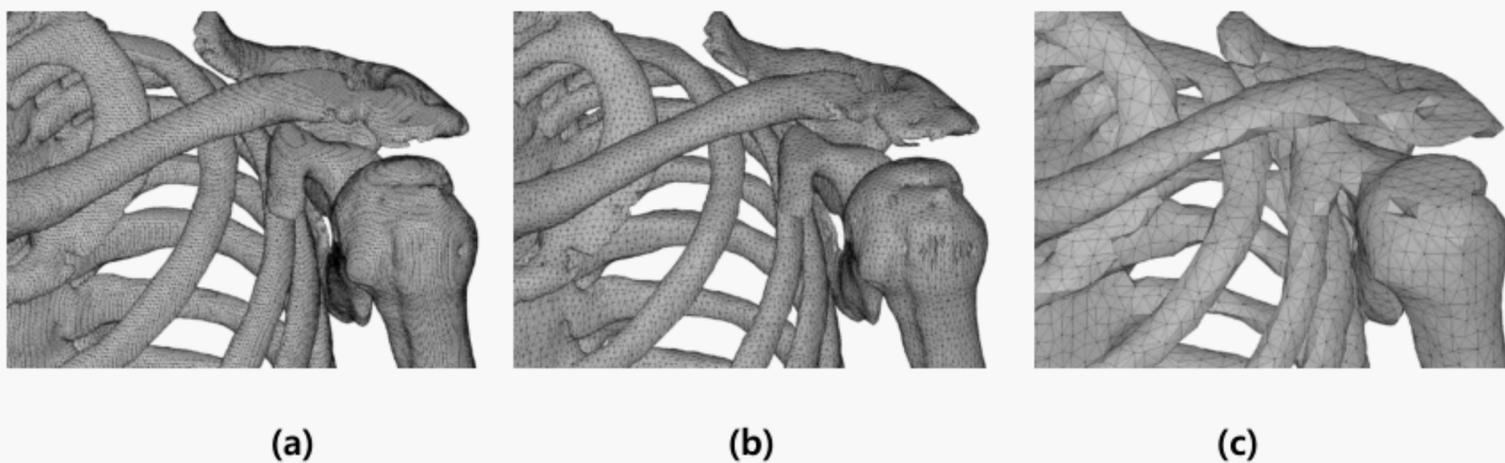
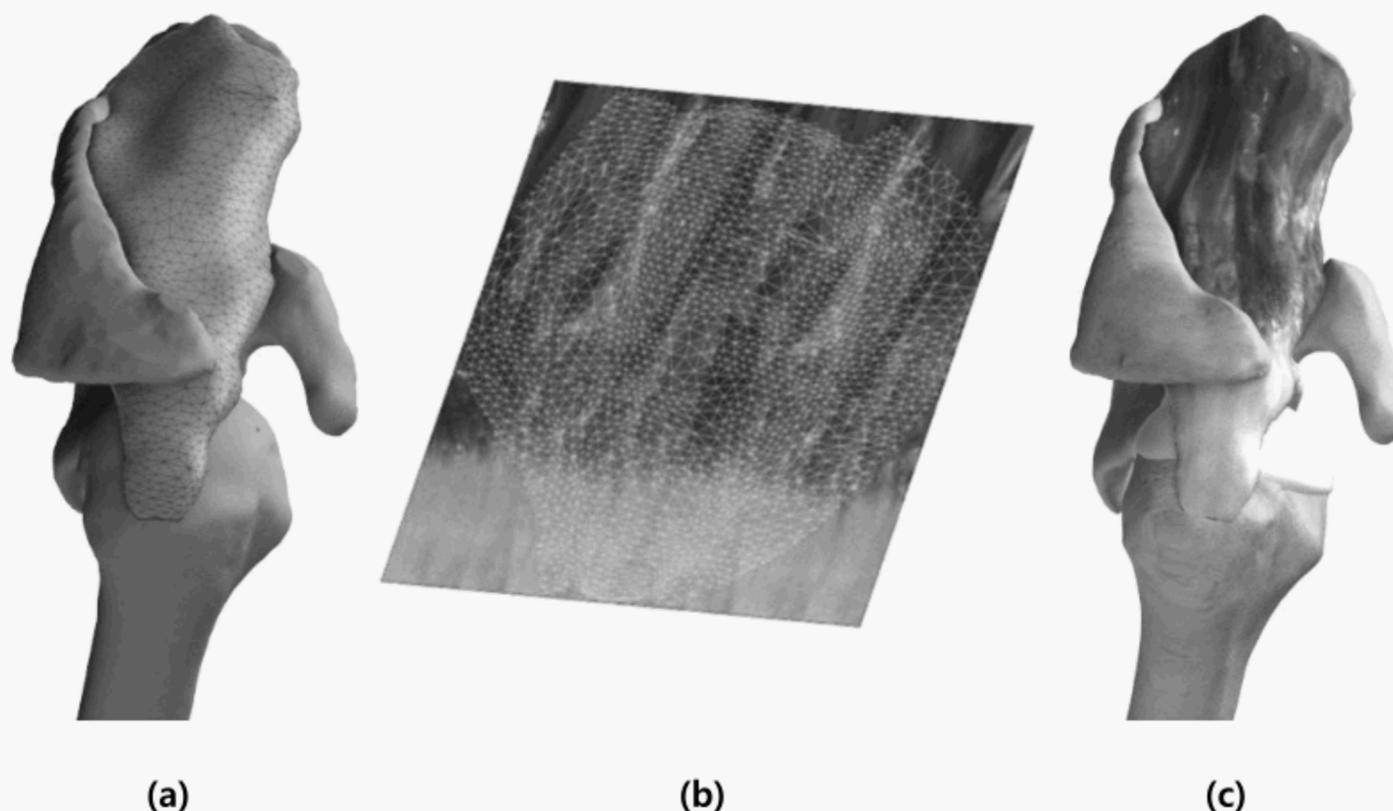


Figure 14—Polygon-reduction procedure: (a) surface model extracted from reconstruction software, (b) polygon was reduced below the preservation of anatomical feature, and (c) polygon was reduced too much. Small anatomical features were removed.

### 5.2.4 3D texture mapping

Medical images have various properties and organization, such as in bones, muscle, and soft tissue. Therefore, using the features of medical images as physical values and visual texturing properties shall result in a more realistic model (see Figure 15).



**Figure 15—(a) Before texture mapping of a surface 3D model.  
(b) Texture source and mapping coordinate.  
(c) After texture mapping of surface 3D model.**

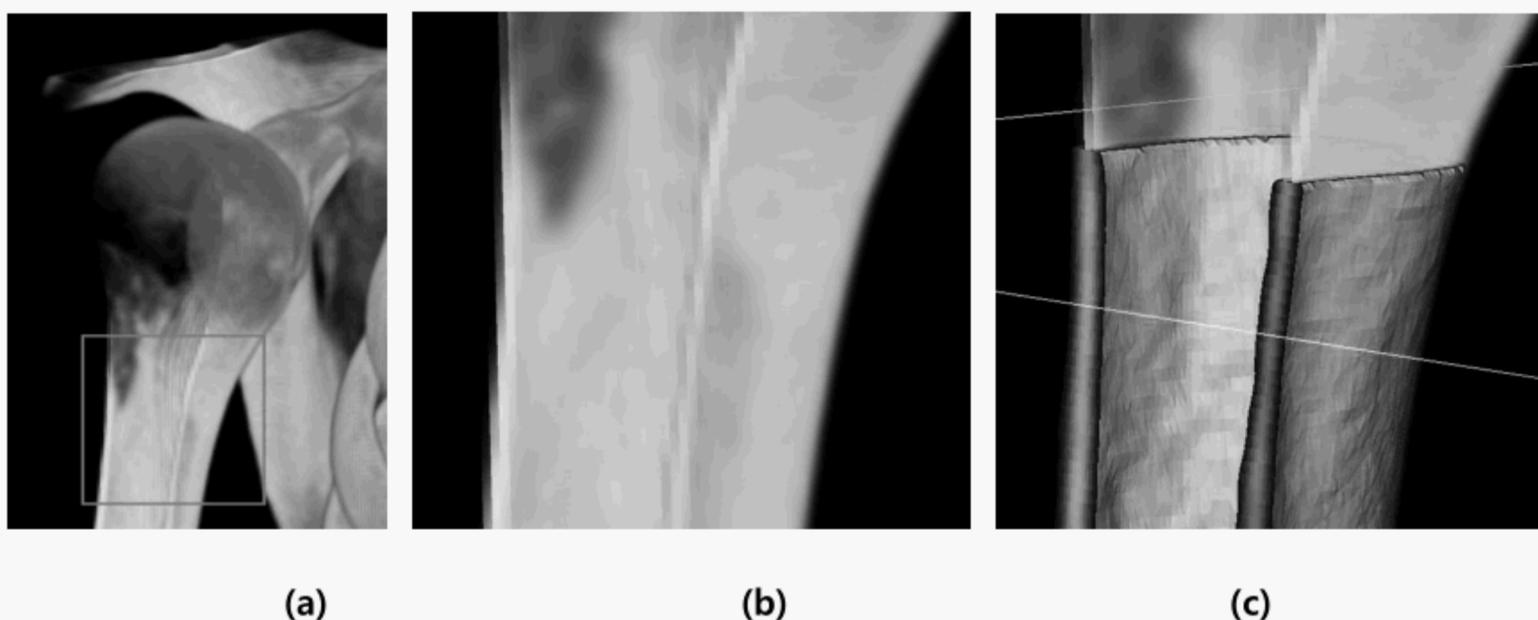
## 5.3 Volume reconstruction

### 5.3.1 Background

Volume rendering is a display of volumetric datasets; therefore, it is able to display all types of data configurations. Even homogeneous regions should be rendered as cloud-like structures. Volumetric datasets are expressed by volume pixel (voxel).

Volume rendering should extract medical information from serial medical images through image processing, which may be useful in many ways. However, in order to do volume rendering, high-capacity information processing is necessary (see Figure 16).

Various techniques have been developed to study volume rendering methods, the most important of which are discussed in the following sections.



**Figure 16—(a) Volume render of humerus vertical section.  
(b) Voxel-level close up.  
(c) Surface 3D model of section extracted from volume 3D model.**

### 5.3.2 Ray casting

Ray casting is the most basic graphics-rendering algorithm that uses the geometric algorithm of ray tracing. Ray-tracing-based rendering algorithms operate in image order to render 3D scenes to 2D images. Geometric rays are traced from the eye of the observer to sample the light (radiance) traveling toward the observer from the ray direction.

Starting from the camera-view position, viewing rays are traced through the data volume. As optical properties are evaluated for every encountered data voxel, the color of every pixel of the final image should be calculated by means of integration. Data volume sampling along with the close viewing of rays is a lengthy process, as it requires interpolation methods to find data values between voxel positions.

Several ray-casting acceleration techniques have been proposed to accelerate the ray-casting process. One optimizing method is that the volume dataset that is not used in the final pixel image is removed. Other techniques to accelerate viewing rays use adaptive sampling techniques [B7].

### 5.3.3 Shear-warp factorization

Shear-warp rendering is capable of generating images of reasonably sized data volumes at interactive frame rates. Nevertheless, a good deal of the image quality is sacrificed. For this reason, several acceleration techniques have been developed, using parallel rendering approaches or optimized sparse data representations.

Additionally, techniques for the hybrid rendering of volume data and polygonal structures based on shear-warp factorization have been introduced. The reasonable speed/quality tradeoff of this technique made it the method of choice for implementation in special hardware architectures [B7].

### 5.3.4 Splatting

Volume rendering implementations are composed by storing “splatted” imprints of data voxels on the image plate. This object-space method proved to be very well optimized by using sparse datasets and other methods, but these methods have problems with aliasing artifacts and research maximum-intensity projection (MIP).

MIP is the rendering technique of choice for vascular structures. Unlike the accumulation process of other volume-rendering techniques, the data volume is not integrated along the viewing direction. Only the maximal data value encountered along a viewing ray contributes to the final image.

Nevertheless, the computational effort of MIP is considerable. Acceleration techniques that work well for ray casting, such as early ray termination or space leaping, will not be employed. For this reason, several other acceleration techniques were developed for MIP. Further enhancements include approaches to improve the 3D impression of MIP renderings, such as depth-shaded MIP or local MIP [B7].

### **5.3.5 Hardware-accelerated rendering (GPU rendering)**

In recent years, hardware-accelerated rendering systems have become available. Classical volume-rendering techniques are implemented to run on dedicated high-performance signal processors. Implemented techniques include volume rendering using 3D textures, parallel volume rendering, and shear warp factorization [B7].

Hardware-based rendering acceleration seems to be a feasible bridge solution for the time being, but as computers constantly increase in power, such dedicated solutions might not be needed. Furthermore, the high-performance components used for accelerators are always custom tailored to the solutions.

For this reason, the accelerators are expensive, need long development times, and try to avoid being overpowered by software-only solutions on PC-based systems, which evolve at a much faster rate than the dedicated hardware solution. Today, hardware accelerators are still a little advanced in terms of rendering performance, but this will change in the near future.

## Annex A

(informative)

### Bibliography

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<sup>2</sup> This publication is available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://ieeexplore.ieee.org/>).

<sup>3</sup> Available at: <http://dk.kisti.re.kr/>

<sup>4</sup> See Footnote 2.

<sup>5</sup> Available at: <http://dl.acm.org/>

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<sup>7</sup> IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

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