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MULTI-DIMENSIONAL TRANSFER FUNCTIONS FOR TISSUE SELECTION IN COMPUTED TOMOGRAPHY

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ABSTRACT

Computed Tomography (CT) is a widely used 3-D imaging technique. A 3-D volumetric grid is obtained from 2-D cross-sectional images. In order to be useful as a diagnostic tool, voxel-based numerical values that represent X-ray absorption in each voxel must be interpreted and combined to form an image that depicts tissue composition at a particular location.

Transfer functions are used to translate measured X-ray absorption data into Hounsfield units, and Hounsfield units into intensities, colors and transparency values. Gradient-based transfer functions are used to highlight material boundaries and interfaces between different tissues. Multi-dimensional transfer functions combine the advantages of regular and gradient-based transfer functions, facilitating a wide spectrum of visual representations.

Transfer functions are usually under user control and often difficult to find. Improper transfer functions can create misleading visualizations and may lead to erroneous diagnoses. This article discusses how multi-dimensional transfer functions can be derived that are clinically relevant and meaningful.

INTRODUCTION

X-ray absorption is usually measured in Hounsfield units, which can be attributed to various substances or tissue types (table 1). CT data files are commonly stored in a 12-bit format (DICOM-3). This means that the values are scaled and stored with a positive offset in a range from 0 to 4095.

For practical purposes, the least significant four bits are often ignored so that the values can be displayed as 8-bit intensity values (256 shades of gray). This method of data reduction is often inappropriate, because values for similar materials, such as bone or teeth, are often close together.

Therefore, we will use the full scanner intensity resolution of 12-bits and an appropriate, non-linear 12-bit transfer function to map the original X-ray absorption values to 8-bit intensity values. Alternatively, another 12-bit transfer function can be used to compute three 8-bit color channels, resulting in 24 bits of color information (16.7 million colors).

In addition to intensity or color transfer functions, we also use a 12-bit opacity transfer function, which maps the original X-ray absorption values to 8-bit opacity values suitable for rendering.

The constraint for 8-bit values is given by a requirement of modern computer graphics cards, which usually operate with 32 bits (24-bit color and 8-bit opacity). This is equivalent to four bytes (3 bytes for color and 1 byte for opacity) per pixel. Each byte represents an integer value between 0 and 255.

On top of using the X-ray absorption values to feed the intensity or color and opacity transfer functions, gradients of X-ray absorption values can be used to detect material interfaces. These boundaries between two substances or tissue types are characterized by a difference in two neighboring X-ray absorption values.

Substance	Hounsfield unit
Air	-1000
Fat	-120
Water	0
Muscle	40
Bone	1000

TABLE 1: HOUNSFIELD UNITS OF COMMON SUBSTANCES AND TISSUE TYPES

The two concepts can be combined into multi-dimensional transfer functions, where the first dimension refers to the original value, and all subsequent dimensions refer to the respective derivatives. For our purposes, we restrict the extra dimensions to a first order derivative, i.e., a differential gradient operator based on two consecutive voxel values. Gradients can be either positive or negative integer values, requiring one extra sign bit for storage.

The motivation for introducing a new concept for finding multi-dimensional intensity or color and opacity transfer functions is the fact that radiologists, unlike computer scientists, are not used to interpreting bits and bytes, i.e., 8, 12 or 32 bit values, or integers between 0 and 255. Instead, it would be useful if transfer functions could be defined based on biological terms, i.e., by means of tissue types.

We present a method that allows radiologists to define a multi-dimensional intensity or color and opacity transfer function based on tissue characteristics, and to adapt the function based on the selected application.

MULTI-DIMENSIONAL TRANSFER FUNCTIONS

The input data for our 3-D visualization algorithm originates from a 12-bit CT scanner. A typical example is shown in figure 1.

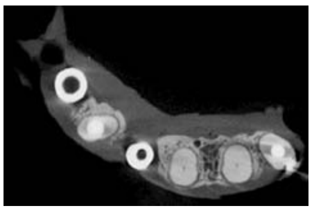

FIGURE 1. TWO-DIMENSIONAL CROSS-SECTION (MAXILLA)

By stacking a sequence of 2-D cross-sectional images and applying a 3-D texture-based volume rendering algorithm [1], a 3-D volume rendering can be obtained (figure 2).

The transfer function in this image was chosen to mimic the real colors of the substances and tissue types scanned by the CT machine. Teeth are represented in white, while bone is slightly yellowish, and the gums were made red. Please note that the image also contains dental implant sockets made of titanium. Since the X-ray absorption values from the CT scanner were saturated, it is not possible to distinguish them from bone, which was represented by the same value.

It has been shown that different scanner models from the same or different manufacturers produce different results. As a matter of fact, even different installations of the same scanner model produce slightly different results. This was demonstrated in a nationwide study, where the same patient was scanned in different MRI machines at different locations [3]. Similar differences exist for CT machines. This is due to differences in calibration, aging of the X-ray source, variances in the detector, etc. Therefore, Hounsfield units do not represent absolute X-ray absorption values, but calibrated values. The correct Hounsfield units are obtained by calibrating a scanner using phantoms.

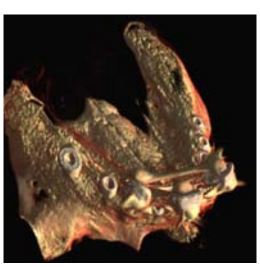

FIGURE 2. 3-D VOLUME RENDERING

The selection of biologically meaningful transfer functions also requires a calibration step. Known tissue types must be used to calibrate the intensity or color and opacity transfer functions. We display a histogram of the X-ray absorption values in a diagram under the transfer function curve. Once markers have been set to separate biologically meaningful tissue types, the transfer function can be changed between each marker pair in order to determine the visual representation (intensity or color and opacity) for each tissue type.

In order to simplify controls, two separate transfer functions are used: one for intensity or color, and another one for opacity. The markers set on one of the two transfer functions are automatically transferred to the other transfer function.

By changing the color and opacity mapping in the given example, we can obtain other, non-photorealistic representations of the same data set. For instance, if the radiologist is interested in the interior structure and density of the bone, the interval of the transfer function that corresponds to bone can be modified so that the bone becomes transparent (figure 3, left). In addition to making bone matter transparent, the color palette for the selected interval can be modified to indicate bone density, which is proportional to X-ray absorption (red=high, yellow=medium, and green=low). This is shown in figure 3 (right).

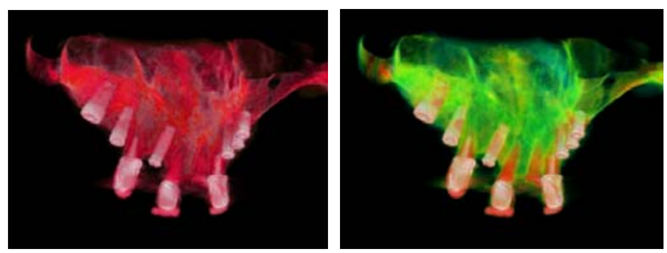

FIGURE 3. TRANSPARENT BONE AND COLOR-CODED BONE DENSITY

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