The reconstruction of three-dimensional models from MR-images for solving problems of radiation therapy

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Abstract

The Magnetic Resonance Imaging (MRI) is popular medical diagnostic technique. Digital Imaging and COmmunications in Medicine (DICOM) is a standard and contains a series of planar images (MRI results). The paper examines the problems of the development of methods for the construction of 3D voxel models of human organs by data obtained using MRI. These models can be used for the research needed for non-invasive methods of treatment. The achievement of this work is a prototype software package, designed for medical physics research.

Keywords: magnetic resonance imaging; DICOM; biological system modeling; GUI; 3D

1. Introduction

In some developed countries, cancer is the leading causes of mortality [1]. This disease can not be treated in the later stages, therefore its early diagnostics are very important.

At present, many hospitals are equipped with medical scanners that provide valuable information, which is necessary for more accurate treatment planning for a particular patient. Magnetic resonance imaging (MRI) is one of the most important imaging techniques that are frequently used due to absence of radiation and high level of soft-tissue contrast. MRI allows imaging in all three mutually perpendicular planes, and in oblique coordinates.

A qualified specialist would have the ability to detect abnormalities in the structure of the body without surgery by viewing the individual images.

MRI is based on the phenomenon of nuclear magnetic resonance. The patient is placed in a constant magnetic field of scanner which contains two powerful magnets. The human body is largely made of water molecules, which are comprised of hydrogen and oxygen atoms. At the center of each atom lies a proton, which is sensitive to any magnetic field. The first magnet causes the body's water molecules to align in one direction. The second magnetic field is then turned on and off in a series of quick pulses, causing each hydrogen atom to alter its alignment and then quickly switch back to its original relaxed state when switched off. The scanner can create a detailed cross-sectional image for the radiologist to interpret. Thus, the information is read from each layer. Tomographic survey results are stored in hospitals in the medical industry standard DICOM 3.0 file [2]. This standard uses its own internal storage technology. Due to the urgency of research of data stored in this format, there is a need of conversion of DICOM images to the three-dimensional geometrical model used in the simulation.

2. The problem of reconstruction 3D-images from DICOM file

Information of scanning is presented in the DICOM format (Digital Imaging and Communications in Medicine), which is the most versatile and the fundamental standard in digital medical imaging. It provides the tools to determine the exact diagnosis and treatment. Moreover, DICOM is a comprehensive network protocol, storing and displaying data built and designed to cover all functional aspects of digital medical imaging. Today DICOM really controls the practical part of the digital medicine.

All actual data - patients, studies, medical devices, etc. - are viewed by DICOM as objects with properties or attributes. The hierarchy of DICOM files is shown on Fig.1.

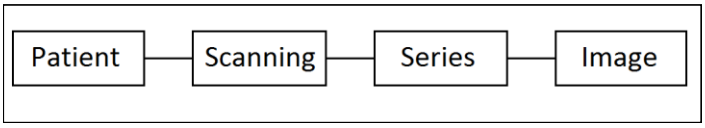

Fig. 1. The hierarchy of DICOM files.

The definitions of these objects and attributes are standardized in accordance with the DICOM Information Object Definitions (IODs). The attributes are a summary description of each specific data object. Patient IOD, for example, can be described by the name, medical record number (ID), sex, age, weight, etc. - any clinically relevant patient information. The patient denotes a set of attributes of which he is composed. DICOM maintains a list of all the standard attributes, known as the DICOM Data Dictionary to ensure consistency of naming and handling attributes. [3]

All numerical data in DICOM is stored in hexadecimal (binary) format.

The primary unit of DICOM is a Data Element (DM), which consists of four compulsory elements and one optional as:
1. Group Number
2. Element Number
3. (optional) Value Representation
4. Value Length
5. Value.

Among the DICOM data it is also advisable to be able to recognize the tags, a full list of which can be found in the specification. For example, if DICOM needs to search for either CT or MR studies it will search by a modality string "CT \ MR". In addition, all information IOD registers in the tags, as it was discussed above.

There are different type of Data Element DM (with/without Value Representation), as you can see in Table. 1,2,3.

Table 1. Data element with Explicit VR of OB, OW, OF, SQ, UT or UN

Tag		VR		Value Length	Value
Group Number (16-bit unsigned integer)	Element Number (16-bit unsigned integer)	VR (2 byte character string) of “OB”, “OW”, “OF”, “SQ”, “UT” or “UN”	Reserved (2 bytes) set to a value of 0000H	32-bit unsigned integer	Even number of bytes containing the Data Element Value(s) encoded according to the VR and negotiated Transfer Syntax. Delimitated Item if of Undefined Length
2 bytes	2 bytes	2 bytes	2 bytes	4 bytes	“Value Length” bytes if of Explicit Length

Table 2. Data element with Explicit VR (other)

Tag		VR	Value Length	Value
Group Number (16-bit unsigned integer)	Element Number (16-bit unsigned integer)	VR (2 byte character string)	16-bit unsigned integer	Even number of bytes containing the Data Element Value(s) encoded according to the VR and negotiated Transfer Syntax
2 bytes	2 bytes	2 bytes	4 bytes	“Value Length” bytes

Table 3. Data element with Implicit VR (other)

Tag		VR	Value Length	Value
Group Number (16-bit unsigned integer)	Element Number (16-bit unsigned integer)	VR (2 byte character string)	32-bit unsigned integer	Even number of bytes containing the Data Element Value(s) encoded according to the VR specified in PS 3.6 and negotiated Transfer Syntax. Sequence Delimitated Item if of Undefined Length
2 bytes	2 bytes	2 bytes	2 bytes	“Value Length” bytes

Some DICOM viewers have the possibility of presenting tomograms only in the form of two-dimensional images, which in most cases allow physicians to make a diagnosis, but some non-classical problems require the study of a three-dimensional model, which can be obtained, "gluing" image-sections. To study the problem of constructing a three-dimensional model, also proves to be insufficient. It is necessary to build and display on the screen not only the form (appearance) of the study area, but also its physical characteristics, such as tissue density.

Three-dimensional (3D) medical imaging it is a vast area in the diagnosis, developed in recent years, which has led to significant improvements in patient care.

The revolutionary possibilities of new methods for 3D medical imaging, along with a computer reconstruction, visualization and analysis of multi-dimensional data volume of medical images provide powerful new capabilities for medical diagnosis and treatment.

3D image processing provides an extensive set of tools for calculating 3D-volume measurement and quantitative analysis. [4]

Diagnosis and surgical simulation can be performed using a 3D model of the patient, and automatically extracted from the identification of anatomical structures.

In addition, the possibility of using augmented reality, you can combine preoperative data with the current state of the organism, or to use them in real-time in the operations.

Most of 3D medical images obtained independently, and the distance between successive slices is greater than the size of a pixel in the plane. Thus, the geometrical dimensions of the voxels that make up the images may be different in the three different directions. In this case, the data element consists of voxels having a base corresponding to the size of the pixel lying in a plane (dictated by the resolution of the scanner) and a height corresponding to the distance between successive slices. Typically, the pixels are square in shape, because of equality of resolution along both axes in a plane.

3. Methods

Application development can be divided into several modules:

- handler DICOM-files (metadata processing DICOMDIR and files *.dcm; receiving of 2d images and patient IOD)
- 2d image processing algorithm (rendering)
- 3D reconstruction method
- 3D image processing algorithms
- GUI development and connection of the required functionality

3.1. 2D Image Processing

DICOM-file Processing was carried out in Python version 3.*, using pydicom package. [5]

The data of each slice in the series are converted to image in *.png format. The color value for each pixel value is replaced by body tissue density data of the tomogram. Note that for MRI DICOM-files store values return signal intensity. It is necessary to take into account additional coefficients - tags "window width" and "window center" in order to get an array of densities, using algorithm [6].

To draw an image, it is necessary to make a comparison the values of the density with the color (Fig.2, Fig 3). This is assignment of the simple transfer function.

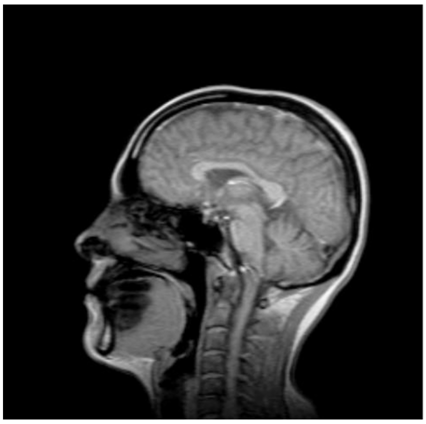

Fig. 2. The result of the work of rendering program (It's one of the standard sample).

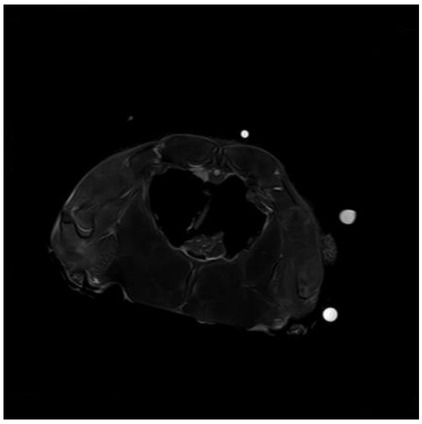

Fig. 3. Image of markered chicken carcass (research to the further program improvement)).

Furthermore, additional information can be added on each 2D-image, i.e. ruler and grid.

3.2. 3D Image Processing

3D reconstruction written in C++ without the use of additional packages. Although it is possible to use a third-party packages. For example, Geant4 (the software package that is efficient in nuclear and medical physics.)[7] has a standard example simulating the interaction of the particles, based on the geometry of DICOM-file. However it has a number of shortcomings, including the format of the output file * .g4dcm, i.e a file containing information about tissues. Thus, to avoid the additional dependencies at this stage it was decided to implement reconstruction of 3d independently.

There are many different methods of 3D reconstruction. This paper used the most common Voxel-based volume model. Voxel - a volumetric pixel, dot element of volume model. The voxel contains a color value (density). The coordinates of each voxel are calculated from its relative location.

DICOM-series are used as the data for processing. Sequence of DICOM-file is clearly defined in DICOMDIR card-file.

Building 3D model involves combining the sequence of images in a particular plane. distance between the images is determined by the orientation of each image in space, as well as its spatial coordinates and thickness of each layer.

The major limitation of the voxel-based volume model is it generates very large data files, requiring huge amounts of computer memory and making the 3D reconstruction process slower.

Choose 3D image processing algorithms - choice of voxel rendering algorithms. (Voxel or volume rendering is procedure of displaying a three-dimensional projection of the model on the screen.)

To reduce the volume of data to be processed when displaying a three-dimensional voxel model on the screen it is advisable to show only those voxels that are not blocked by others. Ray tracing procedure is necessary to determine the voxels situated in front of the camera.

Showing voxels on the screen is produced using OpenGL. (Fig. 4).

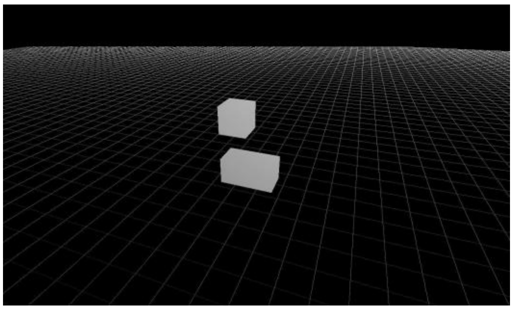

Fig. 4. Voxels rendered using openGL.

Three-dimensional arrays are stored in a simple 3D array, which will allow subsequently, to convert part of calculations in computing on GPU.

OpenGL Shading Language is a high-level shading language with a syntax based on the C programming language. GLSL shaders themselves are simply a set of strings that are passed to the hardware vendor's driver for compilation from within an application using the OpenGL API's entry points.

Using CUDA in the future will optimize the program operation.

3.3. GUI

The graphical user interface at this stage involves drawing arrays on the screen and the ability to work with three-dimensional object (building grid, navigate, zoom). It contains the classic menu toolbar (fig.5). (Some data for tests taken from [8])

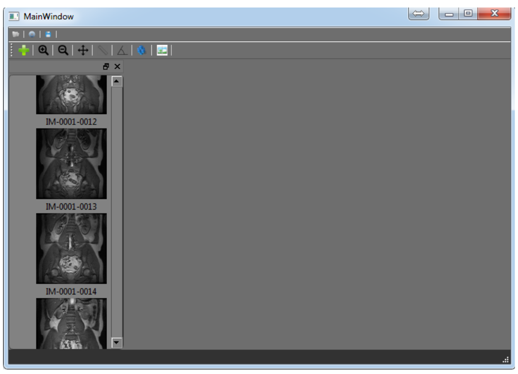

Fig. 5. Operation of the program interface.

The workspace is divided into several parts: a preview window and a window view 3d-image (or 2d).

The interface has the required simplicity. Additional functionality can easily be added as the project progresses.

4. Results and Discussion

DICOM file processing program is written in C ++ and Python, a GUI program in C ++ using the Qt libraries. An algorithm for constructing a three-dimensional model was created. The main idea was analysis of data obtained for all sections of the series. In the case of MRI the space between slices is extrapolated by adjacent slices density. As a result of the algorithm, a set of voxels containing information on the density (intensity) of tissues is obtained.

Three-dimensional model of chicken carcasses (fig. 6) was assembled using the program. In the picture you can see the process of simulation, and the individual layers of tomography are distinguishable. Other examples of the program's work are specified in the main part of the article.

In the future it is planned to expand the functionality by using the tools of software package Geant4 that is for scientific purposes. It is also necessary to optimize the operation of the program, for example, using HPC and parallel programming techniques.

The program can be used in medical purposes for analysis of changes in the body, or in conducting of medical physics research.

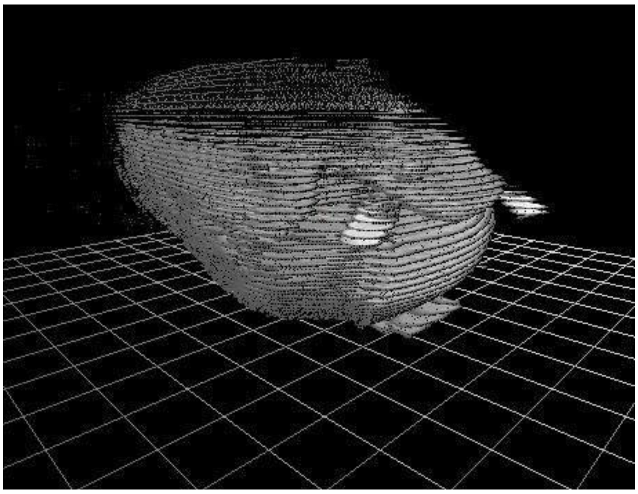

Fig. 6. 3D rendering of chicken model based on MRI.

5. Conclusion

As the result, the GUI application was created. The program allows to read DICOM files and visualize their content, building a two-dimensional image, and creating a three-dimensional ones.

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