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COMPUTER SYSTEM FOR DIAGNOSTIC, INTERVENTION PLANNING AND SURGERY OF BRAIN

The paper presents the computer system for 3D visualization of medical images. The framework of the system and algorithms used for segmentation and visualisation are described. Models of geometric and volumetric visualisation are compared. Additionally, plans for the future system development are stated.

1. INTRODUCTION

Computer systems are widely used in medical research investigations. The image analysing is the one of fundamental sources of information for a diagnostic support then for the disease level recognition, the medical treatment process control or the surgery operations planning. The goal of the described project was building the information system for data processing given by medical image processing devices, such as CT, MRI or PET. The project works are divided into three stages that provide with the aid to the surgical actions into the brain. The presented system includes the following areas of works:

- data acquisition (image data exchange with medical devices).
- diagnostics (filtration, finding and feature recognizing of images).
- planning (Real-time 3D visualization, helping with detecting an illness).
- surgery (Guide system - positioning of medical tools in the surgery area and real-time image presentation).

The scope of the works is schematically described in Fig. 1.

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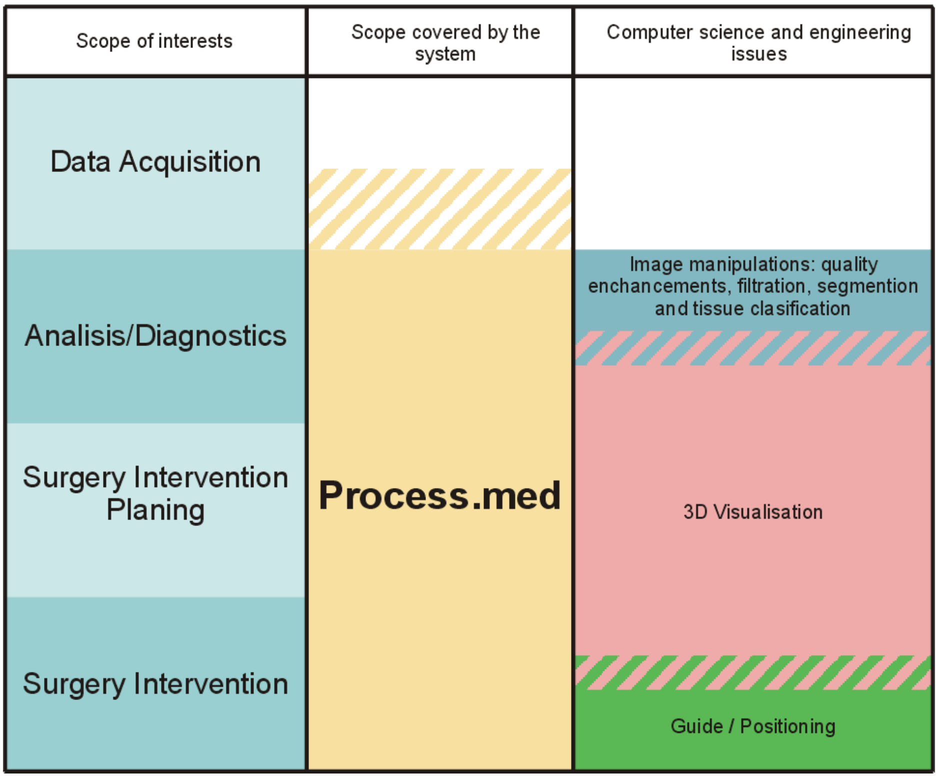


Fig. 1. Scope of interests of the Process.MED system

2. THE DATA SOURCE AND SYSTEM FRAMEWORK

The main source of the image-data is medical image devices such as Computer Tomography (CT), Magnetic Resonance (MRI), or Positron Emission Tomography (PET). Most today tomography devices export data in the DICOM standard [1]. It is very flexible and its construction is publicly available and well described [1], so it is the best choice for medical image data exchange. The main task for the first phase of the system building is to processing images, so that it can be visualised with possibly the highest fidelity as the three dimensional model. This model must be in the form allowing freely rotation in a real time. Because the quality of the input data varies depending on the source, in the first step the image must be filtered to aid further segmentation and classification algorithms. On the second step, the contours of the head or brain are extracted during segmentation. Series of overlapping contours from consecutive image slices are combined into the 3D-Geometry model and is displayed on the screen using the hardware-acceleration. This visualisation is intended for the diagnostics and surgery planning and (later) developed guide-system.

3. FILTRATION AND SEGMENTATION

Image-processing algorithms are used in medicine for finding pathological changes or improving the quality of input images. The Information System “Process.MED” is equipped with various image filters, among others: discrete filters based on Wavelet transformation (DWT), Cosine Transformation (DCT) and Fourier Transformation (FFT), median filters, low and high pass filters and more. Module realizing PCA (Principal Component Analysis) will also be implemented in the near future. The main task of the filtration module is to prepare the image for the segmentation algorithm.

There are many well known methods of the medical images segmentation. One of them is segmentation by area expansion. Starting from a point selected by the user, neighbours are added until reaching the arbitrary stop-condition (given by the threshold value in most cases). The other approach is based on active contours [2][3]. In our application we use, simple but effective edge-detection algorithm, that:

- finds the first point belonging to the edge, moving in one, arbitrary selected direction and compare the current pixel value with the given threshold value;
- repeats the following step until the contour closes: adds to the contour a point laying next to the selected in one of the four directions (left, right, top or bottom). The decision of which direction to choose is taken based on comparing the given threshold and pixel values. As a result, the contour laying on the edge is created.

The main advantage of this algorithm is that the generated contour always describes the coherent area and its points are already placed in the proper order. This is important, because the contour generated by this algorithm is used later for building the 3D model, and the 3D-visualization requires external edges of head and brain.

The algorithm suffers, although, from two major drawbacks: it is difficult to automatically find the starting point, and the results are sensitive to the threshold value, which is also difficult to find without engaging the user of the application. Fig. 3 illustrates different results obtained for nearly the same threshold value (the source image is shown in Fig. 2).

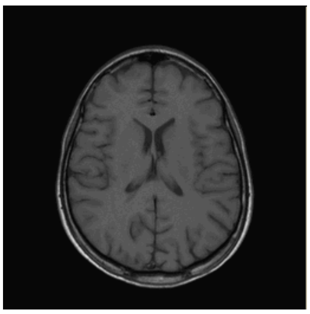
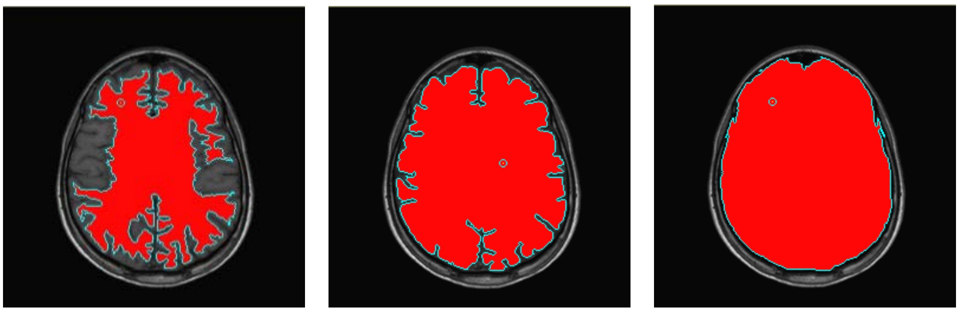


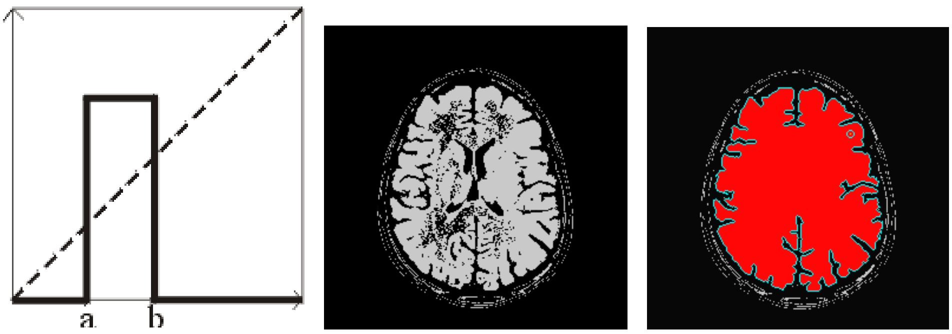
Fig. 2. Source image



(a) (b) (c)

Fig. 3. Different brain areas selected due to different threshold value

We solve the second problem by applying a simple windowing function as shown in Fig. 4.a. The threshold values a, b are obtained by analysing the small section cut from the centre of the image (we assume that the brain is properly, i.e. centrally positioned). As shown in the Fig 4.b, the windowing function converts the greyscale image into the binary one with the brain as the single object, and partial remainings of the other tissues around. Now, the contour algorithm gives more accurate results (compare Fig. 3.b and 4.c), which additionally becomes independent on the threshold value (as we are dealing with a binary image).



(a) (b) (c)

Fig. 4. Simple windowing function (a) applied to the source image (b) makes the results independent on the sensitivity value, increasing the contour exactness (c).

The first mentioned problem (finding a start point) still requires additional investigation. Currently, we obtain the best results using heuristic approach, based on the knowledge about standard brain shapes.

4. 3D VISUALISATION

Important element of the system using results of all other modules (analysis, planning, surgery intervention) is the three dimensional visualization of the data. The approach can be characterized as follows:

- The base input data (sequence of images) comes from MRI/CT scanners. In the future, data from PET scanners should aid the visualization. PET images have lots of information about lesion but they have to small resolution for 3D-visualization.
- Changes in observer position (rotation, zooming) should be realized in a real time.
- Many of the 3D-operations should be available to the user, e.g. free cross-sections and scans, free changes of the transparency and others.
- Visualization should work fast enough on typical PC and notebooks, and it must utilize all available hardware acceleration.

Data from MRI/CT scanners are in the form of volumetric matrices. Dimension of voxels obtained from typical MR devices vary from 1x1x1 mm to about 1x1x5 mm. As our studies shown, this resolution was sufficient for 3D-visualization. There are two possible ways for visualisation of such data:

- Use of volumetric representation directly (this is the most popular procedure in many information systems).
- Use of geometric representation. This method needs additional data processing.

Comparison of both methods is presented in Table 1.

Table 1. Comparison of visualization methods

Volumetric data-based visualization	**Geometric-data based visualization**
Simple data processing	More complex and time-consuming data processing, however the result data (generated mesh) may be written to the file for later usage.
Little probability of data distortion. Data is used in original form.	Advanced algorithms to avoid generation of artifacts are necessary.
No or little hardware acceleration. Slow rendering.	Very high speed of rendering even complex objects due to full hardware acceleration in common video adapters of personal computers.
Average quality of rendering	High quality of rendering

Taking into consideration initial assumptions, the geometric data-based visualization was chosen for our project. Crucial point here is the conversion from volumetric to geometric data, so our work concentrated on this problem.

4.1. PREVIOUS WORKS

Algorithms performing conversion from volumetric to geometric representation can be divided into two groups: spatial- and slice-based. The first group uses some kind of active contours for three dimensional data. In this case, we used surfaces instead of edges. These algorithms are based on minimizing of the surface energy [6-9]. The main advantage of these algorithms is the full utilization of the input data (preserving information of the solid shape in all directions), the main drawback is computing complexity and high memory utilization.

The second group of algorithms based on slices are built of two parts. The detection of shapes is realized in the 2D space (slice-based), where two-dimensional algorithms are used. The edge (or edges) are generated for every slice, and then combined into single solid by another algorithm. Propositions of contours-solid conversion algorithms are presented in [10-13]. Particularly interesting evolution of these algorithms is presented in [14]. The main drawback of these methods is that they loose information about shape in the axis orthogonal to slices. This information is reconstructed later in the second phase of the algorithm, e.g. by interpolation, which increases the probability of distortion. Although this approach has also some advantages, e.g. it utilizes existing and the well-known two dimensional segmentation algorithms, so only algorithm that connects edges into the solid must be implemented. Additionally, when our goal is 3D visualization, it turns out that even a simple connecting algorithm gives good enough results, assuming that the distance between two slices is from 1 up to 5 mm (which is the typical value for MRI scanners).

Slice-based algorithms can be divided into two groups:

- Simple, operates only with one-to-one case (every slice has one contour).
- More complex, taking into consideration one-to-many and many-to-many cases (different number of contours are localised in neighbouring slices. The good example of this case is the „pant's shape" when one contour on first slice splits into two on the next one).

4.2. OUR APPROACH

In our project we used the slice-based algorithm. The input data are sets of contours generated by two-dimensional segmentation. For testing purpose we implemented a simple edge-connecting algorithm allowing only the one-to-one case. The mesh generated is then displayed by hardware-accelerated engine using OpenGL interface. Additionally, to improve the informational value of the visualization without increasing the mesh complication, cross-sections of the rendered solid are filled-up with image data with aid of texturing. Even though the used algorithm is simple, visual effects are very encouraging. The "Process.med" program has been developed in the cooperation with Institute of Radiology, Medical University of Lodz, and is the research platform, where image processing algorithms and methods of visualization are tested. Fig. 1 presents the main window of the program "Process.MED" at work.

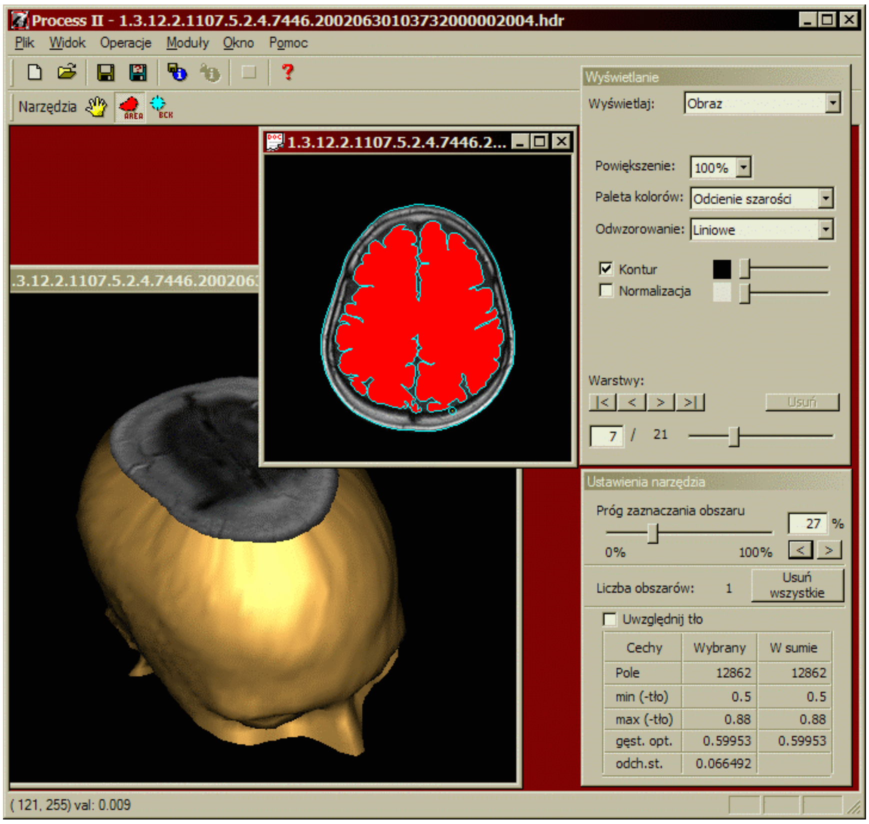


Fig. 5. Main window of the Program "Process.med"

On the first plane cross-section with brain segmented is presented. Behind - 3D-visualization generated by the use of OpenGL interface (Fig. 5).

In the future, the algorithm taking into consideration the many-to-many cases will be implemented and capabilities of generating cross-sections will be enhanced. Additionally, the effect of transparency will be added to the program to enable the possibility of viewing tissues located inside the head.

5. SUMMARY

In the paper, basic elements and features of the system visualizing brain are presented. The advantage of the system is that it can work on usual computers equipped in standard graphic card with "OpenGL" At the moment the system may be applied for planning the surgery and for educational tasks. If equipped in some positioning and navigation mechanism, the system may be applied in real-time during medical operations.

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