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Three-dimensional ROIs in Brain PET

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Abstract. A semi-automatic system for determining volumes of interest (VOI) from positron emission tomography (PET) scans of brain is described. The VOIs surface extraction is based on user selectable threshold and three-dimensional target flood-fill. Contrast to anatomical volume detection approaches, volumes are determined from functional PET images and the obtained objects are checked against anatomical images. The developed VOI program was evaluated with brain FDOPA-PET studies where the striatum was the object. The results were comparable to entirely manual method and the target extraction time is reduced to about one third of manual method.

Keywords: volume of interest, region of interest, positron emission tomography

1 Introduction

Positron emission tomography (PET) images are analysed by drawing region of interest (ROI) from an image and calculating results by using these ROIs. A set of ROIs describing the same object in a volume space constructs a volume of interest (VOI). This can be used to calculate average radioactivity concentration in a homogeneous functional or anatomic structure.

A ROI can be determined by manually drawing areas point by point and plane by plane on the image. Points are connected (in order) by lines to obtain a closed region. With PET images, this manual approach has been reasonable because of the irregularity of target objects, noisy data and relatively low resolution. The anatomic accuracy of a manually drawn region is likely to decrease when the number of subjects and planes grows. Results are also sensitive to the analyser. Relatively more time is spent to the laborious manual drawing task instead of analysing results and making judgments.

Image processing techniques can offer tools for automating parts of this demanding process of outlining objects from medical images. With studies in literature (shortly reviewed in [1]), the time used for target extraction is reduced significantly and the reproducibility of results is superior compared to the results of manual segmentation.

2 Concept to determine volume of interest

The spatial distribution of tissue radioactivity concentration is registered by a PET-scanner and the acquired data is stored to a sinogram. Images are reconstructed from the sinogram. The developed program determines a VOI from the image with the aid of user. The VOI is written out to a file. Average radioactive concentration of a target object is determined from the image by using the obtained VOI. Figure 1 shows the schema of the whole analysis process including data acquisition.

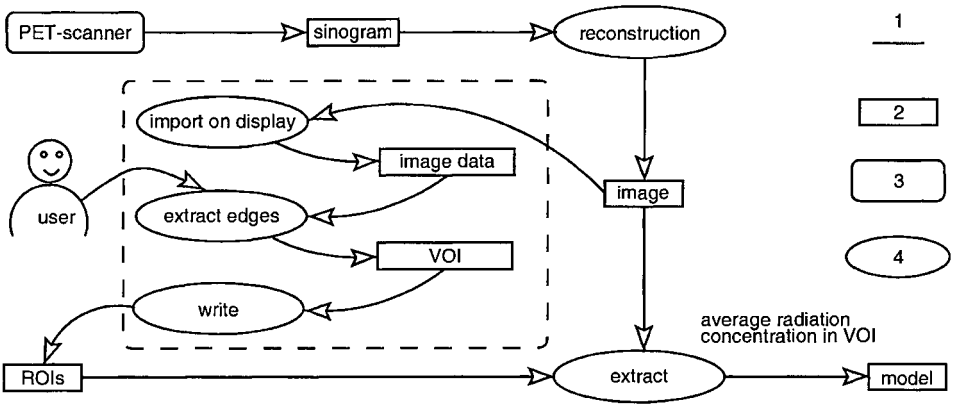

Figure 1: Schema of the analysis process and the data flow. Symbols: 1 data flow and direction, 2 data, 3 active process producing data and 4 action. The dotted box outlines the developed program tasks in the whole analysis process.

The original image is a three-dimensional stack of planes representing spatial distribution of radioactive concentration. The threshold image represents the original image in binary form and it is split to left and right thresholds. The threshold values are set by user. Surface extraction of the functional structure will be done by referring to the threshold image. The user selects a start pixel inside of the functional structure.

A standard flood-fill (region growing) algorithm is used from the start pixel to generate marked image for extracting the surface of object. The surface is described by a set of boundaries on the three-dimensional image. A boundary is extracted from flood-filled image by following the edge on plane by Algorithm 2. All distinguishable boundaries are seeked, extracted and stored as described in Algorithm 1.

Algorithm 1 Find projections of VOI on planes

Set thresholds, select start pixel p_0, and flood-fill object starting from p_0.
for all (marked) planes **do**
  scan all p_i:s from the marked image to find coordinates of projected VOI
  if p_i marked **then**
    Trace boundary by Algorithm 2 and mark traced boundary
  end if
end for
Store obtained projections of VOI.

Algorithm 2 Trace boundary

Get direction d and pixel p_i and set last direction $d' \neq d$.
repeat
  if $d \neq d'$ and $p_j \notin$ boundary b **then**
    add p_j to b, update p_j according to d and d according to neighbourhood pixels of p_j. {Boundary tracing is done counter-clockwise by keeping in pixels on the left-hand side.}
  else
    update p_j according to d
  end if
until $p_j = p_i$ or maximum number of pixels exceed

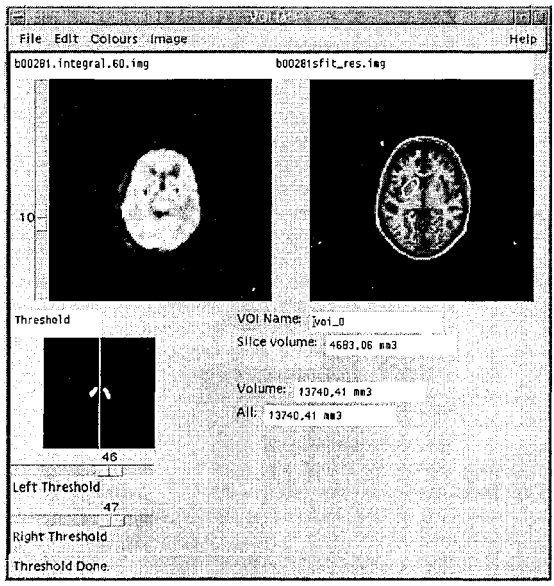

Figure 2: User interface. The upper left image is a user selected plane (transaxial slice) from a three-dimensional image. A vertical slider on the left hand side is used for plane selection. The slider also shows the number of the current plane. The lower image shows the corresponding thresholded version of the current plane. User may select some other plane to view by dragging the slider. The horizontal sliders at bottom are used to adjust threshold levels. The upper right image is optional and is used for verifying results by displaying corresponding ROIs on it. On the lower right part, the current VOI information is shown.

3 Implementation

The program [1] window, shown in the Figure 2, is split to three main parts, menu bar, the data display area and status bar. The data display area includes name of an image file, plane view to an image, vertical slider to select a plane, a plane view to a threshold image, two horizontal sliders to select the threshold values and selected information about the currently defined VOI. Optionally, it is possible to show a second image. The program was implemented by using Sun's Workshop, X11R5, Motif libraries and C/C++ -compiler. The hardware used for development is Sun Ultra 2 with Solaris 2.x.

4 Experiments and results

Experiments of the described concept was carried out in the Turku PET-Centre, Finland. The program was applied to five FDOPA-PET studies and one phantom study. The PET scans were made with ECAT 931/08-12 (CTI/Siemens, Knoxville, USA) scanner. It produces fifteen planes per scan. Magnetic resonance images were obtained with 1.5 T Magneton (Siemens, Erlangen, Germany) PET and MR scans were coregistered by using AMIR [2] method. The phantom PET scan was made with GE Advance (GE, Milwaukee, USA) scanner, which produces 35 planes per scan. The images, except phantom, were reconstructed with a new iterative median root prior (MRP) [3] method. With specific tracer, FDOPA (Fluoro dopa) study has high contrast against background and the visible functional structures can be seen clearly. For example, the

Table 1: Experiments with median root prior (MRP) reconstructed images. Ki is influx constant determined with graphical Patlak analysis.

patient	average Ki value for striatum, $*10^{-2}$ manual ROI method	semi-automatic VOI method	difference VOI-ROI	VOI/ROI volume, cm^3 manual ROI method	semi-automatic VOI method
1	1.04	1.32	+0.28	7.8	29.8
2	1.35	1.25	-0.10	9.3	25.1
3	1.12	1.10	-0.02	11.0	21.5
4	1.05	1.29	+0.24	9.0	14.5
5	0.91	1.04	+0.13	10.0	13.1
average	1.05	1.20	+0.15	9.4	20.8
	average activity, kBq/cm^3			volume, cm^3	
	true	VOI	VOI-true	true	VOI method
phantom	39.5	24.3	-15.2	24.3	23.9

striatum consisting of caudatus and putamen is such a target and it was studied.

With the traditional method, all ROIs are drawn manually on the MR image by using CTI Imagetool program. The ROI positions were evaluated by displaying ROIs on the corresponding PET planes. In VOI method, VOIs were determined from the PET images as described here. The positions of VOI projections were displayed on the corresponding MR images. ROIs and projections are saved for analysis.

Table 1 represents results of analysis and the target object volumes by using the traditional method and VOI method. The time used for extracting VOIs takes about 5-10 minutes per image with manual drawing (ROI), and about 2-3 minutes per image with program (VOI). The volume of phantom striatum is determined by using program and the manual value is the true filled value.

5 Discussion

The volume obtained from VOI method is about three times the corresponding manually determined volume. The manual method boundaries were determined only from two representative planes from the image, while the semi-automatic method finds a true three-dimensional objects from the image causing the difference in volume. Greater volume increases the accuracy of determination of activity concentration. Our tests show about one third time reduction for object extraction, but it is likely to be much better when there are more planes than with the test set of images. Results are reproducible. The simple segmentation method applied is obviously a limitation of the program. It can find the striatum, but cannot split it to its parts. Splitting can be done manually. Automated separation may require a prior knowledge of the structure. With precautions, applying advanced three-dimensional segmentation methods with prior knowledge is certainly interesting topic for further investigation in brain PET.

References

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