Publication II:

Heinonen T, Dastidar P, Kauppinen P, Malmivuo J, Eskola H

Semi-automatic tool for segmentation and volumetric analysis of medical images

Medical & Biological Engineering & Computing, 1998; 36(3): 291-296.

Reprinted with permission from Peter Peregrinus Ltd.

Semi-automatic tool for segmentation and volumetric analysis of medical images

T. Heinonen[1] **P. Dastidar**[2] **P. Kauppinen**[1] **J. Malmivuo**[2] **H. Eskola**[1]

[1]Tampere University of Technology, Ragnar Granit Institute, PO Box 692, 33101 Tampere, Finland
[2]Tampere University Hospital, Department of Radiology, PO Box 2000, 33520 Tampere, Finland

Abstract—*Segmentation software is described, developed for medical image processing and run on Windows. The software applies basic image processing techniques through a graphical user interface. For particular applications, such as brain lesion segmentation, the software enables the combination of different segmentation techniques to improve its efficiency. The program is applied for magnetic resonance imaging, computed tomography and optical images of cryosections. The software can be utilised in numerous applications, including pre-processing for three-dimensional presentations, volumetric analysis and construction of volume conductor models.*

Keywords—*Segmentation, MRI, Volumetric measurement*

Med. Biol. Eng. Comput., 1998, **36**, 291–296

1 Introduction

OWING TO the expanding use of digital imaging methods, such as magnetic resonance imaging (MRI) and computed tomography (CT), the capabilities of image processing are increasing in the field of radiology. For example, digital images enable segmentation, where different tissues and organs are recognised and classified using a computer. Many automatic and semi-automatic methods have been developed for segmenting particular structures (DASTIDAR *et al.*, 1996; FREEBOROUGH *et al.*, 1997; HU *et al.*, 1990; JACK *et al.*, 1989; SAEED *et al.*, 1997; SEUTENS *et al.*, 1993; WAGNER *et al.*, 1995). In this project, we have developed fast, semi-automatic segmentation software for application in any segmentation processing of medical images. The software has been applied to magnetic resonance (MR) images, CT images and optical images of visible human man (VHM) cryosections.

Segmentation procedures were implemented using a combination of basic image processing tools such as filtering, amplitude segmentation (JAIN, 1989), region growing (PRATT, 1991; GLASSNER, 1990), image fusion, etc. Special attention was paid to developing intuitive graphical user interfaces to increase the usefulness of the tools.

Segmented MR/CT images can be analysed and utilised in numerous applications. For example, volumetric analysis of different tissues, lesions and tumours appears to be very useful in clinical research into different diseases. Because the segmented data consist of classified voxels of known dimensions, it is possible to compute the volume of a voxel. Thereafter, the volume of a specific tissue can be easily computed as a product of the number of tissue voxels and the voxel volume. Hence, the accuracy of volumetric analysis depends on voxels size.

Correspondence should be addressed to Dr. Heinonen
First received 23 June 1997 and in final form 15 October 1997
© IFMBE: 1998

Recent literature includes volumetric estimation of plaques and atrophy in multiple sclerosis, volumetric estimation of corpus callosum in diseases of the limbic system, hippocampal volumetric estimation in Alzheimer's dementia and epilepsy, and pre-operative estimation in tumours of the head, neck and body.

Segmentation is also essential for three-dimensional (3D) presentation of anatomical structures (CLINE *et al.*, 1987; DREBIN, 1988) and construction of volume conductor models (HEINONEN *et al.*, 1997; LAARNE *et al.*, 1995).

Any digital image can be used as source data for segmentation, e.g. MR, CT and digital X-ray images. Of these, MR and CT images consist of a set of section images with known dimensions, including thickness of the section. Therefore it is possible to apply volumetric analysis. In planar images, such as X-ray, it is possible to estimate areas rather than volumes. The volume estimation of a single X-ray image can be based on general anatomical knowledge of the shape of some organ, or on pixel intensity, which, in a homogeneous tissue, depends only on the thickness of the organ.

2 Methods

Basic image processing techniques were applied in the segmentation process. Selected techniques, image enhancement, amplitude segmentation, region growing, decision tree (IARD) form the basic tool in all operations, the IARD segmentation procedure (HEINONEN *et al.*, 1997). The idea of IARD is to utilise an appropriate combination of these fast methods to produce a practical medical image segmentation tool.

The first step in the IARD technique consists of three amplitude-segmentation operations, applying appropriate threshold coefficients. The coefficients can be obtained directly from the image histogram or defined manually. The three amplitude-segmented images are presented simultaneously on the screen and can be modified using particular

tools, such as line or rectangle drawing, and filled using connectivity (2D region growing). Various colours represent different tissues. When images appear appropriate, they can be integrated using several decision rules. Another important segment of our semi-automatic tool is an intuitive user interface, which was designed for this particular application.

2.1 *Segmentation techniques*

The software includes the selection of several segmentation techniques for different purposes. These are the IARD method, manual segmentation, 'reloading' and 'lesion tracking.' The IARD method can be applied efficiently in the segmentation of MR images of the human head into scalp, skull, cerebrospinal fluid (CSF), grey matter and white matter of the brain.

If additional tissues are required to be segmented, the reloading method can be used, i.e. already segmented data can be opened and modified again. Reloading has successively been applied for segmentation of a thorax into about 30 different tissues (HEINONEN *et al.*, 1996) and also for accurate segmentation of a head into about 15 different tissues. The lesion tracking method is applicable only when lesions such as tumours are examined. As an additional tool, the manual segmentation method can be used.

The difference between the segmentation techniques concerns the integration of the three amplitude-segmented and pre-processed images. The images are integrated, pixel by pixel, by applying decision trees, i.e. some tissue can cover some other tissues, but not *vice versa*. However, different pixels must first be classified; this can be implemented either by selecting the pixels (or actually a group of pixels representing a tissue) by mouse-controlled cursor or, in some cases, by automatic classification. For example, In IARD segmentation, one amplitude-segmented image is classified semi-automatically to present scalp, skull and CSF. Thereafter, two automatically-segmented images representing grey and white matter of the brain are copied on top of the classified image, applying the following rules:

- amplitude-segmented and pre-processed image number one is selected (including scalp, skull and CSF)
- in amplitude-segmented image number two, a pixel representing the grey matter can be copied to image one only to cover a pixel representing CSF
- in amplitude-segmented image number three, a pixel representing the white matter can be copied to image one only to cover a pixel representing the grey matter
- image number one represents the segmented data.

In lesion tracking, the rules are as follows:

- amplitude-segmented and pre-processed image number one is selected
- a pixel representing a lesion (in images two and three) can always be copied to image one
- pixels representing other tissues (in images two and three) can be copied to image one if they do not cover pixels representing a lesion
- image number one represents the segmented data.

In the reloading and manual methods,

- amplitude-segmented or pre-processed image number one is selected
- a pixel representing a tissue (in image two) can replace any existing pixel on image one
- a pixel representing a tissue (in image three) can replace any existing pixel on image one
- image number one represents the segmented data.

The efficiency of the reloading and manual methods can be increased using priorities, i.e. some particular tissue can cover some other tissue, and *vice versa*. For example, when the human thorax and head are segmented the priorities can be set as follows:

$$\text{thorax: fat} < \text{muscle} < \text{lungs} < \text{cartilage} < \text{bone} < \text{heart} < \text{blood}$$

$$\text{head: scalp} < \text{skull} < \text{CSF} < \text{grey matter} < \text{white matter} < \text{brain lesion}$$

In thorax segmentation, fat has the lowest priority and can be covered by any other tissue; blood has the highest priority and can cover any other tissue etc. Graphical examples concerning the integration techniques are given in Fig. 1.

2.2 *Segmentation tools*

Segmentation tools consist of image filtering, amplitude segmentation, region growing, line and rectangle drawing, free-hand drawing and drawing with a small or large pen. Image filtering consists of a lowpass filter implemented in a 3×3 cross-shaped window using averaging. Such a method appears to smooth the image slightly by decreasing high-frequency details.

Amplitude segmentation is implemented using low and high cutoff thresholds. The result is an image in which the selected pixels are displayed with a uniform colour. The region-growing method was developed using stack functions and operates similarly to fill using connectivity algorithms (GLASSNER, 1990; PRATT, 1991).

Other segmentation tools, such as line and rectangle drawings, were implemented using basic geometrical methods (GLASSNER, 1990). These are used for selection of a region of operation or cutting anatomically connected structures (e.g. MS plaques and ventricles).

Tissue priorities were also applied in filling and drawing operations. The user can choose whether it is allowable to modify colours representing tissues or colour respresenting empty space. That feature appears to be extremely useful in segmentation.

3 Software implementation

The segmentation software, called Anatomatic, was developed on a 32-bit Windows* system, using ANSI C and C++ programming languages. It requires at least 16MB of RAM, minimum 16-bit colours and a minimum resolution of 1024×768 pixels. However, it is recommended to use 32 MB RAM, 24-bit colours, and 1280×1024 resolution. Anatomatic can open, produce, save and display medical images and segmented data. Furthermore, the data can be observed from different projection planes (sagittal, axial and coronal), and volumetric analyses are reported automatically.

3.1 *User interface and operation*

The user interface of Anatomatic appears similar to a bitmap drawing program and is presented in Fig. 2. First, the segmentation technique (IARD, manual, reloading or lesion tracking) is selected. Then, an image stack of MR or CT images is opened and displayed on the screen. The current slice is defined (Fig. 2*a*), and appropriate threshold coefficients are selected (Fig. 2*b*). Thereafter, a segmentation tool

*Windows 95™ and Windows NT™

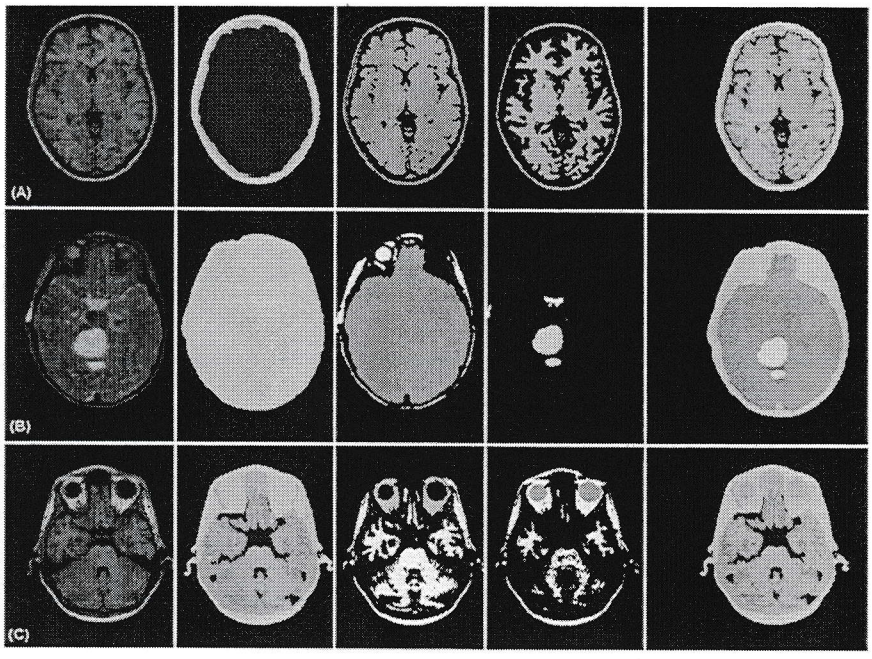

Fig. 1 *Integration of three amplitude-segmented and pre-processed in (a) IARD, (b) manual and (c) reloading segmentation techniques. Source images are presented on left, followed by three amplitude-segmented images. Results of integration is presented on right*

(Fig. 2*c*) and a colour representing a tissue (Fig. 2*d*) are selected, and the images are modified. Once the result appears realistic, the user stores the segmented data (Fig. 2*e*) and begins to process the next image.

The above steps are repeated as many times as there are images in the data set. However, one image can be processed as many times as required, e.g. when several tissues are detected. If the appearance of images is too small, the window can be zoomed. Also, the projection plane can be changed.

The volumetric reports can be displayed at any time during segmentation. The report includes slice-dependent information about the number of voxels and volumes of different tissues, together with the same information about the entire image set. In addition, some parameters are computed automatically, such as brain volume (grey and white matter) and relative atrophy (CSF/brain).

3.2 *Formats*

Anatomatic uses a simple data format to open MR/CT image sets. Any digital image format can be easily converted to this format, consisting of a header and data. In the header, image stack size in x-, y- and z-dimensions and physical dimensions are defined, together with information concerning imaging technique and projection plane. Image data themselves are stored as a 3D matrix using 8 bits per voxel. Internally, the program stores all data structures dynamically and continuously releases the free memory.

Segmented data can be stored and opened in two different formats: raw data and RLE formatted ASCII. Raw format appears similar to the MR/CT image format, in which the original image intensities are converted, with codes representing tissues or empty space. The ASCII format is more advanced, applying different alphabetic codes for different tissues, followed by the number of voxels. Memory use for the ASCII format is on average about 20% of that for the raw format. Volumetric reports can also be stored as an ASCII file, including information on every slice and on the entire data set.

4 Results

Anatomatic was implemented successfully and applied and tested in numerous pilot projects in a hospital environment. Time consumption and the suitability of the methods were estimated in each project. The software was tested in a 120 MHz Pentium-based computer running on the Windows95 operating system. Owing to the interactive character of the segmentation procedure, time consumption strongly depends on the person who controls the segmentation. In our pilot studies, a neuroadiologist carried out all segmentation, and the total time taken for each project was measured. Furthermore, the accuracy of the method was demonstrated by segmenting phantoms of fluid-filled syringes.

4.1 *Pilot studies and time use*

Six epilepsy patients underwent an MR study consisting of 100 axial T1 slices. The images were segmented, using the IARD method, into scalp, skull and CSF and into the grey and white matter of the brain. The segmentation process required about 2–3 h of work for each data set, and the results were anatomically realistic (including the interior of the skull). The results can be studied in Fig. 3, where the segmented data are presented in 2D and 3D. The segmented data were applied in the formation of volume conductors for localisation of the source of epileptic EEG.

An MRI set of a human head (120 slices) was segmented, using IARD and reloading to separate 11 different tissues (scalp, compound of fat blood and muscle, muscle, fat, CSF, bone, aqueous humour, eye lens nucleus, parotid gland,

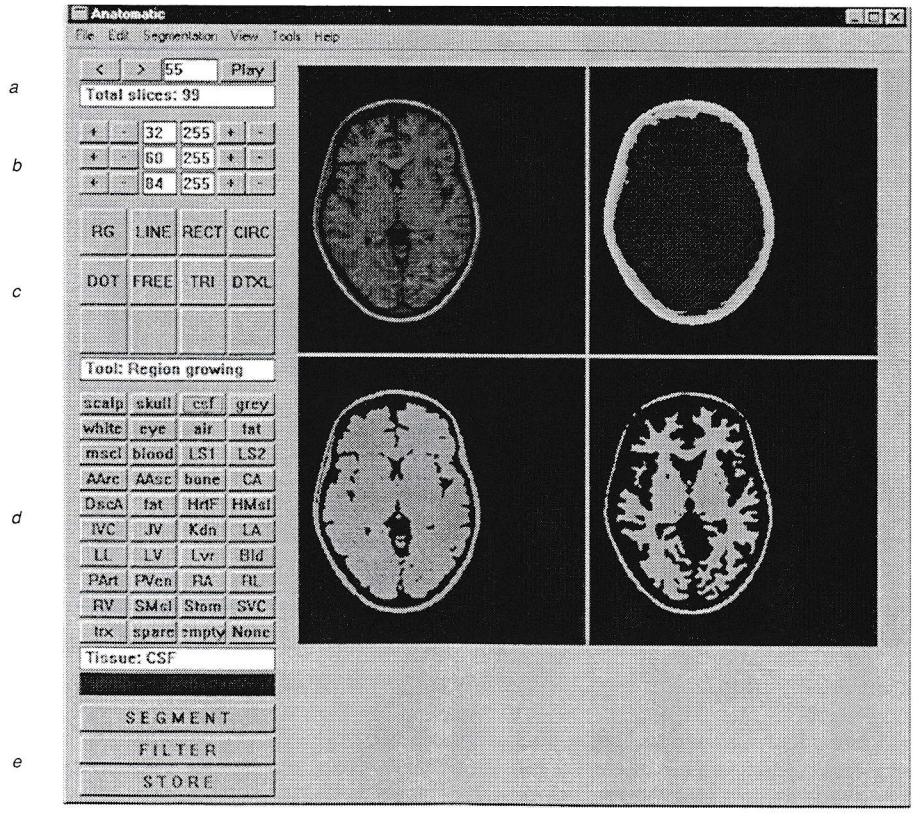

Fig. 2 *User interface of Anatomatic. Segmentation technique and other options can be selected from menus. (a) Current slice is defined by forward/backward buttons and is displayed in upper left corner of window. Three other images are amplitude-segmented images of current slice and can be modified using (b) segmentation tools and (c) threshold coefficient definition. (d) to name the tissue, most common head and thorax tissues are represented by push buttons (e). When results appear realistic, segmented data can be stored*

cartilage and blood). The time taken for the segmentation was about 24 h, and the result was applied in electrophysiological simulations (Figs. 3*e–j*).

28 chronic progressive MS patients underwent a detailed MR study consisting of T1 and T2 MRI (21 slices each for study). The volumes of brain, CSF and MS plaques were estimated for research purposes (e.g. follow-up of patients) using lesion tracking. Depending on the number and locations of plaques, the time taken for segmentation was 5–10 min per MRI set. The brain volume and CSF analysis process was carried out by a radiologist and required 5–10 min per MRI set. The segmentation results appear realistic (Fig. 3*b*).

45 patients suffering right-hemisphere brain infarcts were studied using T2 MRI (21 slices per patient) and thereafter segmented using lesion tracking to obtain infarct, CSF and brain volumes. The process was carried out by a radiologist and required about 5 min per patient, and the results appear realistic (Fig. 3*a*).

VHM cryosection images of the thorax were converted to a set of 250×250 grey-scale images (118 slices) and thereafter segmented using reloading. Images were segmented to 32 separate tissues, such as fat, muscle, heart, liver etc. The result was applied in electrophysical simulations of the electro-cardiogram and impedance cardiogram. The result is a highly accurate volume conductor. Owing to the relatively high number of detected tissues, the time taken was about 16 h (Figs. 3*c* and *d*) (HEINONEN *et al.*, 1996).

Five patients suffering from chronic sinusitis were studied using helical CT. One hundred slices were segmented, and specific volumes of the nasal cavity, paranasal sinuses and pathological soft-tissue changes were obtained. Results were compared with those obtained from rhinometry. The analysis took about 50 min for each patient (100 slices).

4.2 *Phantom test*

The accuracy of Anatomatic was demonstrated by segmenting MR images of fluid-filled syringes. Five syringes with known volume (1, 2, 5, 10 and 20 cm^3) of water were imaged using the T2 weighted MRI sequences (35 slices, 250×250 pixels each). The syringes were fixed on the surface of the quality-assurance phantom. The volume of the phantom, filled with cupric sulphate, was 2000 cm^3, which simulated well the head coil loading during a normal head scan. All the MR images produced were segmented and, according to the measured volumes, the relative error of the total volume based on the syringe images was 1.5%.

5 Discussion

Physicians have found Anatomatic to be useful in studies where volumetric analysis is important, and several medical research projects are currently running. In addition to the established volumetric measurements, which have been proved to be helpful in diseases such as multiple sclerosis,

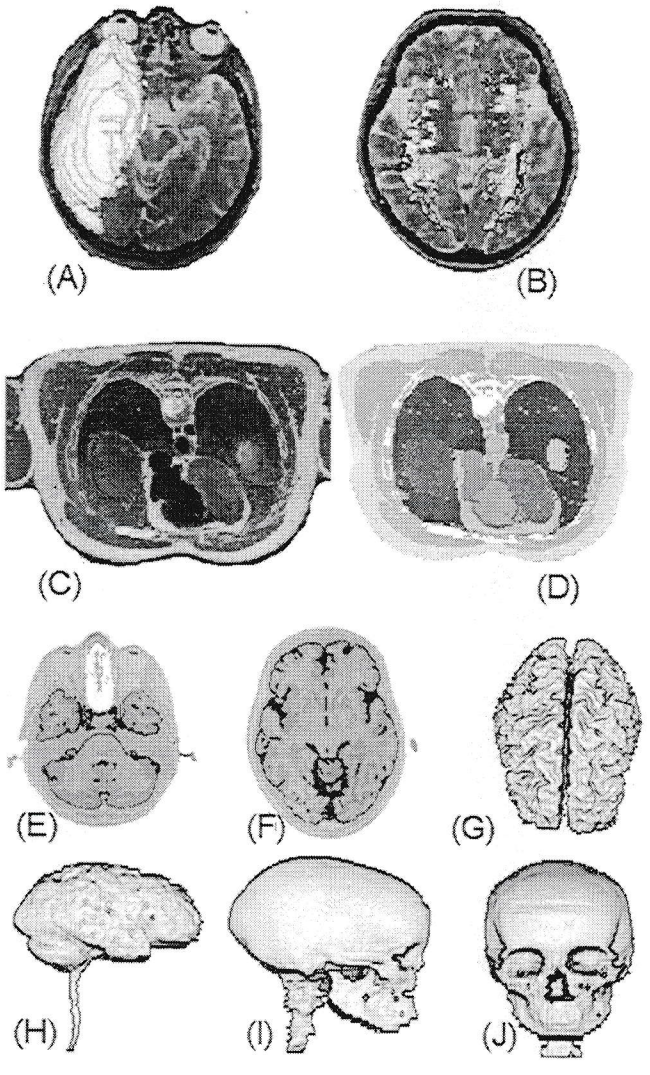

Fig. 3 *Graphical results of segmentation. Axial projections of (a) brain infarct and (b) MS plaques presented on top of MR slice. (c) Axial crysosection of thorax and (d) same segmented cryosection, including fat, muscle, lungs, different blood masses etc. (e), (f) Segmented MR images of head, including scalp, fat, muscle, eye sclera, eye lens, cartilage, aqueous humour, bone, CSF, grey and white matter. 3D presentations of (g) white matter (h) grey matter and (i), (j) skull*

Alzheimer's disease, epilepsy and tumours, we believe that the software could be useful in many other diseases, such as infarcations, intercerebral haematomas, temporal bone diseases, arterovenous malformations, sleep apnoeas, white matter diseases and chronic sinusitis.

Image-analysis tools are often classified as automatic or manual. Because Anatomatic automatically defines the boundaries and combines images corresponding to different tissues, we consider the software semi-automatic. Owing to the semi-automatic character of Anatomatic, it can be used in numerous applications, and unexpected artefacts and anatomical anomalies will not fail the system. However, we are going to develop some automatic algorithms in the future. For example, a detection of MS plaques from FLAIR MRI is under development as a fully automatic and still reliable implementation of IARD to segment the main tissues of the head.

According to clinical tests applied to MS patients, the volume of MS plaques does not correlate with the clinical findings accurately. That can be explained by the probable dependence of the symptoms on the locations of the plaques. Therefore we will develop an anatomical atlas implemented with Anatomatic. Such a method would allow automatic estimation of an impairment caused by a lesion, improving diagnostic capabilities dramatically.

A major problem in quantification is the operator-dependency of lesion measurements, depending on subjectivity in identifying lesions and determining threshold-intensity levels. Therefore intra-observer and inter-observer variation studies are essential in the evaluation of a new imaging and measurement tool. In our study, six physicians will participate in inter-observer studies of lesions in MS and right cerebral hemispheric infarctions. Intra-observer variations will be

performed by an experienced neuroradiologist one week apart, and the intra-observer coefficient of variation will be calculated for the measurements.

Segmentation and volumetric analysis are important radiological tools and, with progressive improvements in seg-mentation, methods will become accessible to daily radiological practices. Also, as neurology and neurosurgery trainees learn neuro-imaging in the most clinically relevant manner (integration of clinical presentation and correlation with the therapeutic outcome of the neuropathologic and surgical findings), we believe that our new segmentation software, with its ease of use, will be in great demand among neurologist and neurosurgeons, bearing in mind the tremendous potential of segmentation and volumetric analysis in the various above-mentioned diseases (BRILLMAN *et al.*, 1997).

References

BRILLMAN, T., KASDAN, R. and WECHSLER, L. (1997): 'The neurologist as neuroimager,' *Neurology*, **48**, pp. 303–305

CLINE, H., DUMOULIN, C., LORENSEN, E., HART, H. and LUDKE, S. (1987): '3D reconstruction of the brain from magnetic resonance images,' *Magn. Reson. Imaging*, **5**, pp. 345–352

DASTIDAR, P., RYYMIN, P.,. HEINONEN, T., PELTOLA, J. and ELOVAARA, I. (1996): 'Semiautomatic technique for measuring lesion volumes using MR segmentation in the treatment and follow-up of multiple sclerosis patients,' *Med. Biol. Eng. Comput.*, **134**, Suppl. 1, (1), pp. 241–242

DREBIN, R. (1988): 'Volume rendering,' *ACM Trans. Comput. Graph.*, **22**, pp. 65–74

FREEBOROUGH, P., FOX, N. and KITNEY, R. (1997): 'Interactive algorithm for the segmentation and quantitation of 3D MRI brain scans,' *Comput. Meth. Progr. Biomed.*, **53**, (1), pp. 15–25

GLASSNER, A. (1990): 'Graphics gems' (Xerox Palo Alto Research Center, Academic Press)

HEINONEN, T., ESKOLA, H., KAUPPINEN, P. and MALMIVUO, J. (1996): 'Tissue segmentation of visible human man data using IARD method,' *Med. Biol. Eng. Comput.*, **34**, Suppl. 1, (1), pp. 139–140

HEINONEN, T., ESKOLA, H., DASTIDAR, P., LAARNE, P. and MALMIVUO, J. (1997): 'Segmentation of T1 MR scans for reconstruction of resistive head models,' *Comput. Meth. Progr. Biomed.*, **54**, (3), pp. 173–181

HU, Z., PUN, T. and PELLGRINI, C. (1990): 'An expert system for guiding image segmentation,' *Comput. Med. Imaging Graph.*, **14** (1), pp. 13–24

JACK, C. ZINSMEISTER, A. and CASCINO, G. (1989): 'Anterior temporal lobes and hippocampal formations: normative volumetric measurements from MR images in young adults,' *Radiology*, **172**, pp. 549–554

JAIN, A. (1989): 'Fundamentals of digital image processing' (Prentice-Hall International Editions)

LAARNE, P., ESKÓLA, H., HYTTINEN, J., SUIKHO, V. and MALMIVUO, J. (1995): 'Validation of a detailed model of the electrical fields in the brain,' *J. Med. Eng. Technol.*, **19**, pp. 84–87

PRATT, W. (1991): 'Digital image processing' (A Wiley-Interscience Publication)

SAEED, N., HAJNAL, J. and OATRIDGE, A. (1997): 'Automated brain segmentation from single slice, multislice, or whole-volume MR scans using prior knowledge,' *J. Comput. Assist. Tomogr.*, **21** (2), pp. 192–201

SEUTENS, P., BELLON, E. and VANDERMEULEN, D. (1993): 'Image segmentation: Methods and applications in diagnostic radiology and nuclear medicine,' *Eur. J. Radiol.*, **17**, pp. 14–21

WAGNER, M., FUCHS, M., WISCHMANN, H.-A., OTTENBERG, K. and DSSEL. O. (1995): 'Cortex segmentation from 3D images for MEG reconstructions, *in* Biomagnetism: Fundamental research and clinical applications (IOS Press, Amsterdam) pp. 433–438

Author's biography

Tomi T. Heinonen was born in Helsinki, Finland, in 1968. He received his MSc degree in electrical engineering and his Lic. Tech. Degree in biomedical engineering from Tampere University of Technology, Tampere, Finland, in 1994 and 1996, respectively. Since 1994 he has been researcher at the Ragnar Granit Institute at the Tampere University of Technology. His research interests include computer sciences, medical image processing, and 3D visualisation of multimodal medical images.