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Editorial

Medical image segmentation: Quo Vadis

This is an exciting time for medical image analysis and processing. For various reasons, image segmentation has been identified as the key problem of medical image analysis and remains a popular and challenging area of research. Image segmentation is increasingly used in many clinical and research applications to analyse medical imaging data sets. Recent developments in image analysis and processing and the increasing interest in medical image segmentation have been covered in many review publications and book chapters (e.g. [1]). The number of papers related to this subject published in peer-reviewed journals and presented at various conferences and symposia has been increasing steadily, which motivated the scheduling of this special issue as a snapshot of the dynamically changing field of medical image segmentation. In parallel, new journals are being launched to respond to the urgent need of handling high quality publications contributing to the advancement of this field (e.g. *International Journal of Biomedical Imaging* (IJBI) [2]).

Many image segmentation algorithms find their foundation in signal processing theory and methods. In a recent editorial, renowned image processing researchers recommended to push science into signal processing by means of comprehensive testing with refutation criteria [3]. Their opinions are pretty valid for the development of image analysis and processing techniques, where image segmentation plays a major role. According to Gordon Moore's famous axiom, the number of transistors on a chip of silicon doubles every year, a prediction changed later to every 2 years. This prediction has been the driving force behind the computer revolution since the early 1980s but now nearing the end of its run. The same can be said regarding the advancement of positron emission tomography (PET) technology where the number of individual crystals in a PET tomograph has doubled approximately every 2 years for the past 30 years (Nutt's Law) [4]. Likewise, the number of proposed segmentation algorithms has doubled every 2 years. There are as many different methods for image segmentation as there are researchers in the field. More in fact, because many researchers have proposed multiple methods.

This special issue of the *Computer Methods and Programs in Biomedicine* is devoted to medical image segmentation techniques and their applications in clinical and research settings. It can be regarded as a preliminary response of our journal to the remarkable challenges in medical image segmentation. Eleven papers [5–15] were selected from 23 submissions as a portrait of its state of the art. The contributions focus particularly on the four major clinical imaging modalities including magnetic resonance imaging (MRI), ultrasound (US), X-ray computed tomography (CT), and nuclear medicine (NM). Two additional papers deal with segmentation of urinary sediments and pupillometric images.

Given the limitations of atlas-based segmentation of MR brain images in the presence of large space-occupying lesions which tend to deform and shift brain structures during the registration procedure, Bach Cuadra et al. [5] focus on the specific problem of inter-subject registration of MR images containing large tumours. Their proposed approach combines a mathematical framework for computing a variational flow with the radial lesion growth pattern proposed earlier by the same authors. Visual assessment of results on patients with meningiomas substantiates the hypothesis that the proposed model overcomes the main limitations of existing methods. Unlike most tumour segmentation algorithms that neglect temporal information, an automated technique using probabilistic reasoning over both space and time allowing to segment brain tumours from 4D spatio-temporal MRI data was proposed by Solomon et al. [6]. An elegant algorithm combining the 3D expectation-maximization method and the Hidden Markov Model to refine segmentation results was developed and validated using simulated and patient studies. The authors demonstrated that this model improves the sensitivity and specificity of tumour segmentation over commonly used spatial or temporal models alone.

In the contribution by Tsantis et al. [7], a hybrid model for segmentation of thyroid nodules using ultrasound images is introduced. The algorithm comprises three main steps: a wavelet edge detection method for speckle reduction and edge map estimation, a multiscale structure model to form significant structures, and finally the Hough transform to distinguish the nodule's contour from adjacent structures. The algorithm was validated through comparison with manual delineations performed by expert physicians demonstrating good agreement between the two techniques. Furthermore, Hodge et al. [8] presented an optimized 2D algorithm based on active shape models for semi-automatic segmentation of the prostate boundary from ultrasound images. They also extended the algorithm to 3D segmentation using rotational-based slicing and validated the approach by comparing segmentation results to gold standard manual outlines. The results show a small difference (∼3%) between the two techniques when using the absolute volume as figure of merit. A different approach was followed by Wu and Sun [9] who proposed a novel technique based on Laws' microtexture energies and maximum a posteriori estimation to construct a probabilistic deformable model for kidney segmentation. They show that kidneys' boundaries of 52 randomly selected clinical B-mode ultrasound images are successfully segmented using this algorithm.

In another hot area of image segmentation – delineation of treatment volumes for radiation therapy treatment planning purposes, Huang et al. [10] describe a method for semi-automated detection of contours in CT images. The method is based on tracking of a contour from a reference image to neighbouring slices. The contours in the reference frame are derived from a set of user defined landmark points, which are interpolated using a Fourier interpolation technique. Tracking the contours to neighbouring slices is based on optical flow as image registration method. On the other hand, the automatic segmentation of cerebral arteries is of clinical importance, especially in the cavernous segment of the internal carotid artery where the vessel is obscured by bone. The method presented by Shim et al. [11] allows to extract cerebral arterial segments from CT angiography images. A particle filter is used as a framework for vessel tracking and is adapted to the detection of arteries in the neighbourhood of bone and veins. They show using experiments on synthetic data that their proposed technique is more robust than conventional vessel tracking methods.

In the contribution by Boudraa et al. [12], a new segmentation method of dynamic nuclear images based on the newly proposed cross-ψ_B-energy operator is described. The algorithm is based on the use of a nonlinear similarity measure (*SimilB*), which quantifies the interaction between two time signals including their first and second derivatives to yield a functional image representing regions with different temporal dynamics. The proposed approach is applied to dynamic nuclear cardiac sequences for visualization and analysis of the ventricular emptying pattern, which proved to be useful in studying motion or conduction abnormalities. The method might also be valuable for other clinical applications, e.g. to improve lesion detectability in oncologic imaging using PET. To deal with the problem of noisy edges segmentation of typical low count nuclear medicine studies, the paper by Barnden et al. [13] report on a noise reduction method consisting in re-projecting reconstructed images followed by searching for edges in the projection count profiles or their spatial derivatives. The algorithm was validated using clinical thoracic FDG-PET, brain and lung perfusion SPECT data sets where the coregistered anatomical (CT or MRI) images served as reference. Stable edges for the four types of data were achieved allowing to conclude that different image types require different edge detection methodology. Best results were obtained using threshold detection for the brain and peak detection for the thorax.

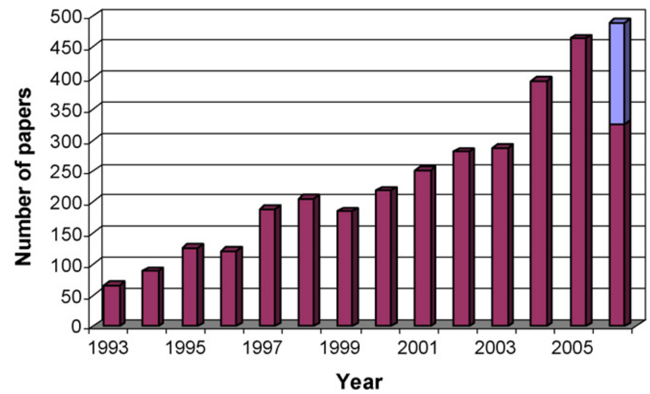

Fig. 1 – Number of peer-reviewed publications of medical image segmentation in a PUBMED search between 1993 and 08/2006. There is a slight decrease in 1999 and a steep increase after 2003. Publications appearing in journals not indexed in PUBMED are not included. Data for 2006 are incomplete (black bar) and show a slight increase compared to 2005 if extrapolated to the end of the year, assuming a similar trend with respect to the first 8 months (gray bar). Search terms: *medical* AND *image* AND *segmentation*.

In the paper by Li and Zeng [14], a strategy combining wavelet transforms with edge detection or adaptive thresholding to obtain segmentation of cellular and acellular components of urinary sediment specimens is presented. The experimental results show that the method can segment the urinary sediment images effectively and precisely, thus increasing the performance of urinary sediment image recognition. De Santis and Iacoviello [15] proposed a fully automated segmentation procedure for determining the pupil morphological parameters from pupillometric data based on the level set theory. The algorithm was validated using frames extracted from sequences of images obtained by a pupillometer from different subjects illustrating its reliability for extracting the pupil from the eye picture and measuring various morphological parameters, such as pupil diameter, centroid, and area.

The development of medical image segmentation and other image analysis techniques have been very rapid and exciting, and there is every reason to believe the field will move forward more rapidly in the near future with the advent of better computing power and the unlimited imagination of researchers in the field. Despite the remarkable results reported in this special issue and other peer journals (Fig. 1), there is still scope for further research. There is no shortage of challenges and opportunities for medical image segmentation techniques nowadays. I hope that in this limited space I was able to give you a flavour of multi-modality medical image segmentation techniques and their potential applications in clinical and research settings. I found compilation of this special issue to be a rewarding and educational experience and hope that the reader is left with the same experience.

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