Advances in Medical Image Computing

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Summary
Objectives: Medical image computing has become a key technology in high-tech applications in medicine and an ubiquitous part of modern imaging systems and the related processes of clinical diagnosis and intervention. Over the past years significant progress has been made in the field, both on methodological and on application level. Despite this progress there are still big challenges to meet in order to establish image processing routinely in health care. In this issue, selected contributions of the German Conference on Medical Image Processing (BVM) are assembled to present latest advances in the field of medical image computing.
Methods: The winners of scientific awards of the German Conference on Medical Image Processing (BVM) 2008 were invited to submit a manuscript on their latest developments and results for possible publication in *Methods of Information in Medicine*. Finally, seven excellent papers were selected to describe important aspects of recent advances in the field of medical image processing.
Results: The selected papers give an impression of the breadth and heterogeneity of new developments. New methods for improved image segmentation, non-linear image registration and modeling of organs are presented together with applications of image analysis methods in different medical disciplines. Furthermore, state-of-the-art tools and techniques to support the development and evaluation of medical image processing systems in practice are described.
Conclusions: The selected articles describe different aspects of the intense development in medical image computing. The image processing methods presented enable new insights into the patient's image data and have the future potential to improve medical diagnostics and patient treatment.

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1. Introduction

Medical image processing applications have become an ubiquitous part of modern imaging systems and the related processes of clinical diagnosis and intervention. Over the past years significant progress has been made in the field, both on methodological and on application level. Despite this progress there are still big challenges to meet in order to achieve systems that are more robust, more accurate and more intuitive to interact with [1, 2].

To address these problems, the German conference on Medical Image Processing (Bildverarbeitung für die Medizin, BVM) has been established. Since 1993 the BVM is held annually with participants from engineering

and computer science, medicine and industry [3–5]. In 2008 the BVM was hosted by the Charité – Universitätsmedizin Berlin with 200 participants. In this issue seven awarded BVM 2008 contributions are assembled to present some of the latest advances in the field of medical image processing.

2. Trends in Medical Image Computing

The scope of new developments in the field is broad. Therefore, the contributions in this issue can reflect only some of them. Nevertheless, a number of core areas are addressed: acquisition, registration and fusion, visualization and simulation, segmentation and validation. The primary application areas for the new or enhanced methods range from general improvements for an entire class of imaging devices or tasks to the support of either the diagnosis and treatment planning or the intervention for different medical specialties (vascular diseases, abdominal and cardiac surgery, neurology and neurosurgery).

The developments in image acquisition can be considered from two viewpoints: The engineering of novel imaging devices and the methods for processing raw data to compute images, volumes and corresponding type series [6, 7]. One major trend is the tremendous increase of the number of images-per-patient studies, particularly for multi-detector computed tomography. To keep the radiation dose delivered to the patient in an acceptable range, the computational methods for processing raw data must become dose-efficient.

Addressing a key challenge progress in image registration and fusion is an important prerequisite for advances in computer-aided diagnosis and image-guided intervention [8–10]. Robust and fast methods for acquisition of morphological and functional (molecular, metabolic) information in a unified reference coordinate system both for visualization and for further utilization in the clinical process are needed. Due to the complex mechanical properties of soft tissue in many applications such as abdominal surgery, nonlinear elastic registration methods are of high relevance. Following the general attempt in medical image processing of making analysis methods more robust against missing values and variations, the registration of corresponding points in images from a certain body region of the same patient acquired with different modalities or from different patients with the same modality becomes a powerful method when replacing exact correspondences by iteratively evolving correspondence probabilities. Models built on the basis of such correspondences can also improve the robustness of model-based segmentation approaches [11, 12]. The challenging fusion of volumetric ultrasound with 3D-radiography for a combined visualization of cardiac morphology and function has shown to be feasible.

Major advances in the field of visualization and simulation address more accurate reconstruction of surfaces. Optimized density and quality of triangles locally adapted to the degree of surface complexity are one of the goals to achieve. The surface quality must be especially high if the surfaces are used for dynamical simulations, since even small artifacts on the surface may cause large disturbances. New accurate and high-quality reconstruction methods for vascular structures could help paving the way for blood flow simulation.

In the field of image-guided intervention, recent advances extent the scope of applications from a surgical target with rather rigid geometry, such as brain surgery, towards surgical targets with the ability of large movements and distortion both between planning and doing surgery, and also during the surgery procedure, as this is the case for example in the abdominal surgery. Particular attention has to be paid on validation of systems for image-guided intervention. In this context, physical phantoms play an important role. With their exactly defined and known geometry they provide the assessment base line within the validation procedure. With respect to this, new radiologic phantoms for the simulation of respiratory liver motion are used for the validation of image-guided liver surgery systems.

3. Selected Contributions

It was not an easy task for the editors to select the best and simultaneously most representative papers in this colorful collection of the conference topics: segmentation and registration tools for clinical diagnosis and therapy, imaging methods, data visualization and fusion techniques, robotics, sensors, intelligence networks for medical decision-making, patient care and biomedical simulation and its enabling technologies, haptics and modeling.

A fundamental problem when building a statistical shape model (SSM) is the correspondence problem. In [13] an approach for unstructured point sets is presented where one-to-one correspondences are replaced by correspondence probabilities between shapes which are determined using the Expectation Maximization – Iterative Closest Points registration. Experimental results of synthetic data and brain structures as well as a performance comparison with a statistical shape model built on one-to-one correspondences show the efficiency and advantages of this approach.

A key technique for protein analysis is the geometric alignment of 2D gel electrophoresis (2DE) images. A new hybrid elastic registration approach for 2D images which is based on analytic solutions of the Navier equation is introduced in [14]. With this approach cross-effects in elastic deformations can be handled. 2DE gel images of different levels of complexity are registered successfully. Quantitative evaluation of the results has been performed. Furthermore, the new approach was compared with the hybrid registration scheme that das been used previously.

Due to current demographic development, the use of computer-assisted diagnosis (CAD) systems still becomes an important part of the clinical workflow and clinical decision making. Changes on the mucosa of the esophagus indicate the first stage of cancerous development. Therefore, the automatic detection of such lesions is of great interest. In [15] a knowledge-based system is presented to support a physician with the interpretation and diagnosis of endoscopic images of the esophagus and demonstrated it in clinical routine with convincing success.

Research of visual perception of luminance differences is an important basis for understanding the perception of complex patterns. A new approach for determining the contrast sensitivity function (CSF) in front of the complex anatomical structures of mammograms is introduced in [16]. For this purpose, a sinusoidal pattern and digits are used

as target items. The approximation to contrast thresholds is done by a psychological staircase procedure and is performed for a selection of spatial frequencies.

Quality refinement of software systems developed for usage in clinical routine is also of considerable importance. In particular, since novel regulatory affairs apply on software that is used in patient care the development of software must obey new rules. On October 11, 2007 a new guideline 2007/47/EG of the European Parliament was activated that changes older laws on medical products 93/42/EWG and on active medical implants 90/385/EWG. All software for diagnostic and/or therapeutic support is now considered a medical product and must therefore be developed under quality management rules and certified (including e.g. HIS and PACS). In [17] a process to advance quality aspects of existing research prototypes in order to prepare them for clinical studies is presented and evaluated. The proposed process is tailored for research environments and therefore easier to use than traditional quality management processes. An improved quality of all investigated prototypes is demonstrated resulting in significantly reduced development times.

Another core problem in a broad variety of application contexts is the task of segmentation. Continuous progress has been made towards sophisticated, more robust and (semi)automatic segmentation methods.

Segmentation of the left ventricle (LV) is required to quantify LV remodeling after myocardial infarction. Therefore, spatiotemporal cine MR sequences including long- and short-axis images have to be analyzed. A new semiautomatic segmentation method for fast and robust segmentation of the left ventricle that considers the position of the mitral valve and the apex as well as the long-axis contours to generate a 3D surface model is presented in [18].

In consequence of the increasing amount of image data, automatic methods for segmentation and motion estimation are required. In adaptive radiation therapy, registration techniques are used for the estimation of respiratory-induced motion of pre-segmented organs. In [19] a variational approach for the simultaneous computation of 3D images from the sequence with improved accuracy is described. The success of the proposed method is demonstrated on four-dimensional thoracic CT images of the liver and the simultaneous estimation of its respiratory-induced motion field.

4. Conclusions

In conclusion, we observe that the field of medical image processing is under rapid development with more accurate and more robust methods and applications for a broader range of medical specialties. The contributions in this issue are examples of how the efforts towards creating a more complete, multi-modal insight into the human morphology and function are taking place in current research and development.

At BVM, where we are privileged to explore and act at the forefront of medical methodology, answers emerge. Creating and utilizing data networks to design human well-being is not an abstract vision of the future; it is the challenging task of every day. In these imbalanced times, when harsh realities dominate personal and public dialogue, we congratulate BVM researchers on their successes and continuing determination.

References

1. Handels H, Ehrhardt J. Medical Image Computing for Computer Supported Diagnostics and Therapy – Advances and Perspectives. Methods Inf Med 2009; 48: 11–17.
2. Lehmann TM, Aach T, Witte H. Sensor, Signal and Image Informatics, State of the Art and Current Topics. Methods Inf Med 2006; 47 (S1): 57–67.
3. Horsch A, Deserno TM, Handels H, Meinzer HP, Tolxdorff T. IJCARS Special Issue Editorial, BVM 2007 German Conference on Medical Image Processing. Int J CARS 2008; 2: 253–254.
4. Handels H, Horsch A, Meinzer HP. Advances in Medical Image Computing. Methods Inf Med 2007; 46: 251–253.
5. Lehmann TM, Meinzer HP, Tolxdorff T. Advances in Biomedical Image Analysis, Past, present and future challenges. Methods Inf Med 2004; 43(4): 308–314.
6. Werner R, Ehrhardt J, Frenzel T, Säring D, Lu W, Low D, Handels H. Motion Artifact Reducing Reconstruction of 4D CT Image Data for the Analysis of Respiratory Dynamics. Methods Inf Med 2007; 46 (3): 254–260.
7. Oehler M, Buzug TM. Statistical Image Reconstruction for Inconsistent CT Projection Data. Methods Inf Med 2007; 46 (3): 261–269.
8. Kabus S, Franz A, Fischer B. Spatially Varying Elasticity in Image Registration. Methods Inf Med 2007; 46 (3): 287–291.
9. Ehrhardt J, Säring D, Handels H. Structure-preserving Interpolation of Temporal and Spatial Image Sequences Using an Optical Flow Based Method. Methods Inf Med 2007; 46 (3): 300–307.
10. Haber E, Modersitzki J. Intensity Gradient Based Registration and Fusion of Multi-modal Images. Methods Inf Med 2007; 46 (3): 292–299.
11. Heimann T, Wolf I, Meinzer HP. Automatic Generation of 3D Statistical Shape Models with Optimal Landmark Distributions. Methods Inf Med 2007; 46 (3): 275–281.
12. von Berg J, Lorenz C. A Geometric Model of the Beating Heart. Methods Inf Med 2007; 46 (3): 282–286.
13. Hufnagel H, Pennec X, Ehrhardt J, Ayache N, Handels H. Computation of a Probabilistic Statistical Shape Model Optimizing a Global Criterion. Methods Inf Med 2009; 48: 314–319.
14. Wörz S, Winz ML, Rohr K. Geometric Alignment of 2D Gel Electrophoresis Images. Methods Inf Med 2009; 48: 320–323
15. Münzenmayer C, Kage A, Mühldorfer S, Wittenberg T. Computer-assisted Diagnosis for Precancerous Lesions in the Esophagus. Methods Inf Med 2009; 48: 324–330.
16. Apelt D, Strasburger H, Rascher-Friesenhausen R, Klein J, Preim B. Generalizing the Evaluation of Medical Image Processing Tools by Use of Gabor Patterns. Methods Inf Med 2009; 48: 331–335.
17. Neuhaus J, Maleike D, Nolden M, Kenngott HG, Meinzer HP, Wolf I. A Quality-refinement Process for Medical Imaging Applications. Methods Inf Med 2009; 48: 336–339.
18. Säring D, Relan J, Groth M, Müllerleile K, Handels H. 3D Segmentation of the Left Ventricle combining Long- and Short-axis MR Images. Methods Inf Med 2009; 48: 340–343.
19. Schmidt-Richberg A, Handels H, Ehrhardt J. Integrated Segmentation and Non-linear Registration for Organ Segmentation and Motion Field Estimation in 4D CT Data. Methods Inf Med 2009; 48: 344–349.