

Image Analysis and Modeling in Medical Image Computing

Recent Developments and Advances

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Keywords

Medical image computing, image analysis, image-based modeling, model-based image segmentation, image registration

Summary

Background: Medical image computing is of growing importance in medical diagnostics and image-guided therapy. Nowadays, image analysis systems integrating advanced image computing methods are used in practice e.g. to extract quantitative image parameters or to support the surgeon during a navigated intervention. However, the grade of automation, accuracy, reproducibility and robustness of medical image computing methods has to be increased to meet the requirements in clinical routine.

Objectives: In the focus theme, recent developments and advances in the field of modeling and model-based image analysis are described. The introduction of models in the image analysis process enables improvements of image analysis algorithms in terms of automation, accuracy, reproducibility and robustness. Furthermore, model-based image computing techniques open up new perspectives for prediction of organ changes and risk analysis of patients.

Methods: Selected contributions are assembled to present latest advances in the

field. The authors were invited to present their recent work and results based on their outstanding contributions to the Conference on Medical Image Computing BVM 2011 held at the University of Lübeck, Germany. All manuscripts had to pass a comprehensive peer review.

Results: Modeling approaches and model-based image analysis methods showing new trends and perspectives in model-based medical image computing are described. Complex models are used in different medical applications and medical images like radiographic images, dual-energy CT images, MR images, diffusion tensor images as well as microscopic images are analyzed. The applications emphasize the high potential and the wide application range of these methods.

Conclusions: The use of model-based image analysis methods can improve segmentation quality as well as the accuracy and reproducibility of quantitative image analysis. Furthermore, image-based models enable new insights and can lead to a deeper understanding of complex dynamic mechanisms in the human body. Hence, model-based image computing methods are important tools to improve medical diagnostics and patient treatment in future.

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1. Introduction

Medical image computing techniques have become increasingly important in modern medical diagnostics and therapy. Nowadays, a variety of image computing and visualization techniques is used in daily routine. However, further developments are needed to increase the grade of automation, accuracy, reproducibility and robustness of image computing methods [1–8].

Image-based modeling techniques and model-based image analysis methods are important tools for robust and automated segmentation and quantitative analysis of image objects like organs, vessels, and tumors. On the one hand the models use a-priori knowledge about the images structures (bones, tissue, tumors, etc.), on the other hand models and important features can be extracted from image data automatically by image-based modeling techniques. Moreover, image-based modeling enables the analysis of the dynamic behavior inside the body and e.g. the measurement of the blood flow or a prediction of tumor growth becomes possible.

2. Methods

For the focus theme, selected authors of the Conference on Medical Image Computing BVM 2011 in Lübeck were invited to submit a manuscript on their latest developments and results for possible publication in this focus theme. Invitation was based on their outstanding presentation and the blinded peer review process of the conference. After international reviewing of the journal submissions, finally seven excellent papers were assembled to describe several important aspects of recent advances in the field of image-based modeling and model-based image analysis in medical image computing.

3. Results

The selected papers give an impression of the high variety of methods used in this challenging field and show interesting results in different medical applications.

In the first three papers [9–11] different model-based segmentation approaches are presented to delineate image objects of interest automatically and with high accuracy and robustness. In [9] dual-energy CT images are analyzed to compute the spatial distribution of bone mineral density in vertebrae as an indicator for osteoporosis. During the analysis, the model-based segmentation of regions of interest is an essential step. Here, active shape models are applied using shape information of the segmented image structures during the segmentation process. Deformable models are used in [10] to support diagnosis and treatment assessment of knee joint osteoarthritis. In a two step approach, implants and bones are segmented in radiographic images using deformable template models as a prerequisite of the following automatic joint alignment measurements. In a study, the automatic extracted measures showed a high accuracy and precision. The improvement of brain vessel segmentations in three-dimensional time-of-flight magnetic resonance angiography images is the main goal of the graph-based method described in [11]. The method can be considered as an extension of the segmentation approach described in [12]. A given vessel segmentation is improved by closing the gaps between vessel fragments, which are typically located at small vessel structures exhibiting low image intensities. A graph-based approach is applied to detect and model knowledge on gaps between vessel parts. In combination with a level set segmentation method connections between vessel fragments are detected and gaps in cerebrovascular segmentations are closed, automatically.

A novel method to model the uncertainty of blood flow computation in phase-contrast magnetic resonance imaging is presented in [13]. The approach incorporates the uncertainties of the measurements into the computation of particle trajectories in an anisotropic fast marching method. The analysis results enable the simultaneous visualization of the structure and the uncertainty of the particle trajectories. In [14] a novel computational framework for modeling tumor induced brain deformation is presented. The model is based on the assumption that the pro-

gression of the primary brain tumor is governed by proliferation on the one hand and migration of cancerous cells into surrounding healthy tissue on the other hand. The model opens up the possibility to simulate tumor growth in patient data and will be used to improve non-diffeomorphic image registration of images of brain tumor patients. A toolkit for the model-based analysis of diffusion MRI images is presented in [15]. The algorithms are implemented as an extension of the Medical Imaging Interaction Toolkit (MITK), called MITK-DI. The open source toolkit MITK-DI provides a comprehensive software framework for model-based analysis and interactive data exploration of diffusion MR images. In the last contribution of this focus theme, the use of models in the field of microscopic cell image analysis is illustrated [16]. Morphological features are extracted and analyzed automatically with the goal to detect adaptive mitosis of in vitro stem cell tracking data. Different morphological cell features are considered and their influence to the automatic recognition of mitotic events and non-mitotic track irregularities using support vector machines is evaluated.

4. Discussion

The selected papers give an impression of the breadth and heterogeneity of new developments in the field of model-based medical image computing. New methods for model-based image segmentation, for modeling of tumor growth as well as methods for quantitative analysis e.g. to measure the distribution of blood flow velocities in a vessel are assembled. These methods were developed and optimized to facilitate and extend the analysis of medical images and to extract significant quantitative parameters describing characteristic image or object features.

In the focus theme new approaches for the model-based segmentation and analysis of dual-energy CT images [9], radiographic images [10], time-of-flight, phase-contrast and diffusion MR images [11–15] as well as microscopic cell images [16] are presented as examples of the development in this challenging field.

The contributions of the special issue show the breadth of the development in the interdisciplinary field of model-based medical image computing and illustrate the wide application range in medicine. Model-based image analysis and image-based modeling methods presented enable new insights into the patient's image data and will contribute to improve medical diagnostics and patient treatment in future.

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