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Synopsis

Medical Image Processing: New Perspectives in Computer Supported Diagnostics, Computer Aided Surgery and Medical Education and Training

Medical image processing has become one of the most important fields in medical informatics. In the past, with the introduction of tomographic imaging techniques like computer tomography, magnetic resonance imaging, positron emission tomography etc. the amount of digital medical images has increased rapidly. Moreover, the availability of the DICOM standard for medical images has facilitated image handling and image exchange, especially between radiological departments and scientific image processing groups. Nowadays, basic image processing and visualisation techniques are used in daily routine. However, high-level image processing methods are needed to analyse and visualise anatomical and pathological image structures in a user-oriented mode, especially if a large number of images for one patient containing spatial, anatomical and functional information are available. Moreover, 4D image processing algorithms are required to analyse the temporal signal changes in a whole body volume, if temporal 3D image sequences have been generated.

In the last years, 3D image processing has become a key technology for operation planning and computer aided surgery. The rapid development of computer hardware in combination with the enormous decrease in hardware prices significantly facilitated the development and introduction of 3D image processing techniques in clinical environments. Image processing tools will be an essential part of the operation room of the future: Operations will be planned in the virtual patient body and interventions will be done using image based navigation systems as well as surgical robots. In [1] the fascinating possibilities of the use of an image based tele-robot system in surgery are demonstrated in the field of urology.

High-level image processing techniques are needed to improve medical diagnostics, operation planning and image guided surgery. The impact of new developments in image processing on these fields can be illustrated by the development of registration algorithms. Registration algorithms have offered new possibilities for the analysis and visualisation of multimodal image data sets. Using these algorithms, image data from different imaging modalities like radiography, ultrasound, computer tomography, magnetic resonance imaging, functional magnetic resonance imaging, positron emission tomography etc. can be matched and represented in a common coordinate system of a reference body. Hence spatial, anatomical, and functional image information usually distributed over a huge number of images can be visualised in one common 3D scene showing key anatomical structures, pathological tissue changes, functional brain regions, and their spatial correlation to each other. These new image processing methods enable completely new insights into the patients image data improving medical diagnostics and patient treatment. Impressive results of the clinical use of registration algorithms in neurosurgery are given in [2].

Furthermore, image based 3D models of human organs and tissues can be used to develop and to verify biophysical models describing the state and behaviour of tissues and organs in terms of quantitative parameters like strain, elasticity, and so on. These models can provide the physician with a new quality of information. An interesting example illustrating the value of simulation models is given in [3], where the regional cardiac deformation from 3D ultrasound image sequences is described using a biomechanical model. Alternatively, 3D models of the human body in combination with anatomical knowledge can be used to generate a digital anatomical atlas of the human body. In [4] an impressive description of an atlas based 3D learning environment is given, which offers new possibilities to study the human anatomy in virtual bodies with fascinating photo-realistic 3D images.

The development of image analysis systems for diagnostic support, operation planning and computer aided surgery is a very complex interdisciplinary process. On the one hand, new image processing methods have to be developed to support the physician during the diagnostic and therapeutic process. On the other hand, methods of different scientific fields have to be adapted and used in combination: Image analysis algorithms need to be applied in combination with methods of pattern recognition, mathematics, computer graphics, simulation, and robotics. The four selected papers give an impression of the breadth and heterogeneity of new developments in the field of medical image processing.

The paper by Abbou et al. [1] describes the use of the robotic system DA VINCI during a laparoscopic radical prostatectomy in urology. The DA VINCI system consists of two main parts: a slave unit placed by the patient in the operation room and a master unit located in an area adjacent to the operating room. Both are connected by a computer based system. The slave unit consists of a surgical cart with a camera arm, instrument arms and a vision cart. The surgeon directs the robot at the master unit consisting of the surgeon console and an integrated 3-dimensional display stereo viewer. A stereo camera generates stereo images of the inner organs for image based navigation of the surgeon. The instrument tips viewed in the display are aligned with the master to ensure natural and predictable instrument movements. The authors show that the system has proven to be ideal not only for remote surgical demonstration and practical teaching, but also for tele-robotic surgery. A special advantage of the system was that hand tremor was eliminated during the operation. In summary, it was demonstrated by the authors that robotically assisted laparoscopic radical prostatectomy is feasible and that the robot provided an ergonomic surgical environment and remarkable dexterity enhancement.

In the paper by Gering et al. [2] an image processing system for surgical planning and guidance using an open interventional MR system is described. This paper is a fascinating report on the integration and the use of high level image processing tools in neurosurgery. It describes the possibilities and advantages for patient treatment, if 3D image processing algorithms including segmentation, registration and 3D visualisation algorithms become available in clinical routine. Registration algorithms are applied to align multimodal image sequences in one common coordinate system. In the considered application, pre-operative data (T1- and T2-weighted MR images, MR angiography images, functional MR images) are fused. Each of these image sequences contains different information about the patient: While T1- and T2-weighted images show the same brain tissues with different contrast, in MR angiographies the vessel system of the brain is strongly enhanced. Furthermore, in fMR images the individual localisation of the patient's brain functions can be displayed.

Key anatomical structures like tumour, vessels, ventricles, skin, brain, and functional regions have to be segmented. This is done in different data sets, e.g. the vessels are extracted in the MR angiography while the functional regions are separated in the functional MR data set. A 3D surface model can be generated automatically for each segmented structure. After the registration step, it is possible to visualise the segmented vessels, functional regions, brain, tumour etc. in one 3D scene. Furthermore, pre-operative images are aligned to images generated by an open MRI during the intervention. In the application, only rigid registration methods compensating rotations and translations between the data sets are applied, and local deformations like brain shift effects are not taken into account. However, Gering et al. report that rigid registration was sufficient in the considered cases. The system has been applied in 45 neurosurgical cases and found to have beneficial utility for planning and guidance.

The paper by Papademetris et al. [3] deals with a new approach for the model based estimation of quantitative parameters to describe the regional cardiac deformation from 3D ultrasound image sequences. In a first step, the images are segmented interactively and a dense displacement field is estimated using a Bayesian estimation framework. The dense motion field is in turn used to calculate the deformation of the heart wall in terms of strains in cardiac specific directions using a biomechanical model. The computed strain data are compared with data measured in open-chest dogs with implanted sonomicrometers, which were considered to be the gold standard. The strains computed in the 3D ultrasound image sequence exhibit a high correlation to the measured sonomicrometer derived strains. With this innovative approach the authors open up new perspectives to model the biomechanical behaviour of the left ventricle.

The system presented by Pommert et al. [4] has been developed to support medical education and training. A high-resolution, digital 3D atlas of the human body was described based on the visible human image data set of the National Library of Medicine. Three-dimensional models of anatomical structures have been generated and visualised in high quality to give a fascinating insight into the spatial inner structure of the human body. In the paper, an excellent survey on the methods applied in the 3D atlas system is given. A symbolic description is used to give the user information about the relationships of anatomical structures to each other. Hence, image processing methods and knowledge representation methods are applied in combination. The authors describe the techniques to make anatomical knowledge available during the photo-realistic 3D visualisation of anatomical structures. Through the combination of anatomical and radiological image information with anatomical knowledge, the atlas opens up a new intuitive way to a deeper understanding of the structure of the human body as well as to the interpretation of radiological image data.

References

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