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Guang-Zhong Yang
Tianzi Jiang (Eds.)

Medical Imaging and Augmented Reality

Second International Workshop, MIAR 2004
Beijing, China, August 2004
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Preface

Rapid technical advances in medical imaging, including its growing application to drug/gene therapy and invasive/interventional procedures, have attracted significant interest in close integration of research in life sciences, medicine, physical sciences and engineering. This is motivated by the clinical and basic science research requirement of obtaining more detailed physiological and pathological information about the body for establishing localized genesis and progression of diseases. Current research is also motivated by the fact that medical imaging is increasingly moving from a primarily diagnostic modality towards a therapeutic and interventional aid, driven by recent advances in minimal-access and robotic-assisted surgery.

It was our great pleasure to welcome the attendees to **MIAR 2004**, the 2nd International Workshop on Medical Imaging and Augmented Reality, held at the Xiangshan (Fragrant Hills) Hotel, Beijing, during August 19–20, 2004. The goal of **MIAR 2004** was to bring together researchers in computer vision, graphics, robotics, and medical imaging to present the state-of-the-art developments in this ever-growing research area. The meeting consisted of a single track of oral/poster presentations, with each session led by an invited lecture from our distinguished international faculty members. For **MIAR 2004,** we received 93 full submissions, which were subsequently reviewed by up to 5 reviewers, resulting in the acceptance of the 41 full papers included in this volume. For this workshop, we also included 4 papers from the invited speakers addressing the new advances in MRI, image segmentation for focal brain lesions, imaging support for minimally invasive procedures, and the future of robotic surgery.

Running such a workshop requires dedication, and we are grateful for the generous support from the Chinese Academy of Sciences. We appreciate the commitment of the MIAR 2004 Programme Committee and the 50 reviewers who worked to a very tight deadline in putting together this workshop. We would also like to thank the members of the local organizing committee, who worked so hard behind the scenes to make **MIAR 2004** a great success. In particular, we would like to thank Paramate Horkaew, Shuyu Li, Fang Qian, Meng Liang, and Yufeng Zang for their dedication to all aspects of the workshop organization.

In addition to attending the workshop, we trust that the attendees took the opportunity to explore the picturesque natural scenery surrounding the workshop venue. The Fragrant Hills Park was built in 1186 in the Jin Dynasty, and became a summer resort for imperial families during the Yuan, Ming and Qing Dynasties. We also hope some of you had the time to further explore other historical sites around Beijing including the Forbidden City, the Temple of Heaven, the Summer Palace and the Great Wall. For those unable to attend, we hope this volume will act as a valuable reference to the MIAR disciplines, and we look forward to meeting you at future MIAR workshops.

August 2004

Max Viergever, Xiaowei Tang,
Tianzi Jiang, and Guang-Zhong Yang

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New Advances in MRI

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Abstract. Since its initial use in humans in the early 1980s magnetic resonance imaging (MRI) has become a widely used clinical imaging modality. Nonetheless, there continue to be opportunities for further advances. One of these is improved technology. Specific projects include high field strength magnets at 3 Tesla and beyond and an increased number of receiver channels for data acquisition, permitting improved SNR and reduced acquisition time. A second area is the further study of image formation, including the manner of sampling "k-space" and the specific type of image contrast. A third area is the in-creased exploitation of high speed computation to allow every-day implementation of techniques other-wise limited to research labs. Finally, MR is growing in its usage as a non-invasive, reproducible, and quantitative test in the study of non-clinical questions. MRI continues to be an area with a wealth of opportunity for contemporary study.

1 Introduction

Over the last two decades magnetic resonance imaging (MRI) has become a widely accepted technique useful for the clinical depiction of many types of pathologies of the brain, spine, abdomen, and musculoskeletal and cardiovascular systems. The significance and impact of this can be seen in various ways. For example, currently there are approximately 15,000 whole body MRI units installed worldwide with approximately 7,000 of these installed in the United States [1]. With a very conservative estimate of ten clinical examinations per scanner per day, this converts to well over 100,000 MRI exams daily around the world. Another measure is the continuing growth of clinical MRI. Although there have been year-to-year variations, over the ten-year period from 1992 to 2002 MRI at Mayo Clinic grew at a 10.4% annual rate, and this is typical of many institutions. Yet another measure of the significance of the modality was the awarding of the 2003 Nobel Prize in the category of Physiology or Medicine to two pioneers in MRI development, Drs. Paul Lauterbur and Peter Mansfield. By each of these measures MRI has become significant in modern medicine around the world.

In spite of this success and clinical acceptance there is still ample room for MRI to grow technically and scientifically. The fundamental limitations of MRI, primarily the limits in the acquisition speed and the signal-to-noise ratio (SNR), have still not been adequately addressed in many applications. Also, the fundamental technical

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advantages of MRI over other modalities, such as the high degree of contrast flexibility and the arbitrary nature in which an image can be formed, can be further exploited.

The purpose of this work is to describe several contemporary trends in the ongoing technical development of MRI. These include advances in technology for providing improved MRI data, advances in the manner of sampling MRI data acquisition space or "k-space," computational techniques for facilitating the high-speed formation of MR images, and advances in the manner in which MRI is used as a scientific tool.

2 MRI Technology

2.1 Increased Magnet Strength

Selection of field strength is one of the most important choices in defining an MRI system, as it drives many of the other aspects of the system, such as siting, available contrast by virtue of the field-dependent relaxation times, and intrinsic SNR. In the mid-1980s MRI manufacturers developed systems at a field strength of 1.5 Tesla, and this became the *de facto* maximum operating strength which was routinely available. Since that time a number of applications have been identified as potentially benefiting from higher strength, such as *in vivo* MR spectroscopy, functional neuro MRI using BOLD contrast, and SNR-starved applications such as those using various fast-scan techniques. The advantages of higher field are offset by increased specific absorption rate (SAR) and decreased penetration of the RF field into the body. To address this interest, MR vendors in approximately the last five years have developed systems at 3.0 Tesla for routine installation. Additionally, whole body systems have been developed for individual research laboratories at 4, 7, 8, and 9 Tesla. The advantages of such systems in the applications indicated above are in the process of being studied. It remains to be seen to what extent these advantages trigger widespread installation.

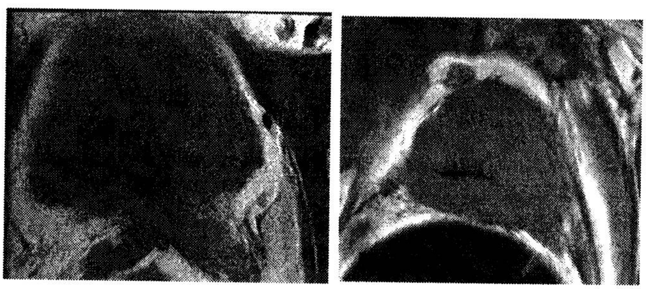

Fig. 1. Comparison of image of prostate at 1.5 Tesla (a, left) and 3.0 Tesla (right). Note the improved SNR of the latter due to the increased field strength. The same T1-weighted spin-echo sequence was used for both

An example of the advantages of 3.0 Tesla is shown in Figure 1. Figure 1a is an image of the prostate of a human cadaver acquired at a field strength of 1.5 Tesla. A four-element surface receiver coil was used in conjunction with a 12 cm FOV and

256x256 spin-echo imaging sequence. Fig. 1b is an image of the same specimen using the same pulse sequence and scan parameters as for (a) but now at a field strength of 3.0 Tesla. The improvement in SNR is readily apparent, measured in this study as 2.1X. Results such as these may increase the clinical applicability of MRI in these anatomic regions as well as in other areas in which SNR can be limiting. A specific example is high resolution imaging of the hand. In these cases it is critical that appropriate receiver coils be used which are not only tuned to the increased resonant frequency but also matched to the anatomic region under study.

2.2 Improved Receiver Channels

Another area of technology in which there has been considerable recent development is in the receiver chain of the MRI scanner. Receiver coils have long been a field of study in MRI. Early developments included developing a single "coil" consisting of several distinct coil elements, the signals from which were added prior to digitization and reconstruction [2]. In ca. 1990 multi-coil arrays were developed in which a separate image was made from each individual coil element, the results then added in quadrature to improve SNR [3]. With this approach the signal from each receiver element was directed to an individual receiver channel, and typically the number of such channels was limited to four. However, recently there has been interest in expanding the number of such receiver channels, as motivated by the desire for further gains in SNR, broader anatomic coverage, and the implementation of various parallel imaging techniques. Thus, modern, top-of-the-line scanners are equipped with 8, 16, and even 32 individual receiver channels. Additional flexibility is provided by allowing for coil arrays with even more elements than the number of channels. Switching is allowed to direct a specific element to a specific receiver.

Figure 2 is a comparison of a coronal scan of the abdomen using a single-shot fast-spin-echo technique, the result in (a) acquired using a standard four-element phased array, that in (b) formed using a modern eight-element coil with eight receiver channels. The pulse sequence was identical for the two scans. The result in (b) is clearly superior in SNR.

3 MR Image Formation

3.1 k-space Sampling Techniques

The measured signal in MRI samples the Fourier transform of the final image. This is often referred to as "k-space." Early theory showed that the time integral of the gradent waveforms was proportional to the specific k-space position being sampled. Thus, customized gradient manipulations could provide very precise k-space trajectories. Over time, the most commonly used method has been a 2DFT technique in which an individual line is sampled each repetition of the acquisition, the final image formed from a data set comprised from a set of such parallel lines. However, other trajectories have also been developed in the last two decades, most notably radial or projection reconstruction (PR) and spiral. Each has its specific advantages and limitations. However, recently further variants in these have been developed, in some cases allowing for time-resolved imaging.

One example of a such a technique is time-resolved imaging of contrast kinetics or "TRICKS" [4]. This is a 3D acquisition method in which the central portion of k-space is sampled periodically, and outer regions are sampled less frequently. The final image set is reconstructed from the most recent measurement of each phase encoding view. Because of the difference in sampling rates, the actual rate at which images are formed is greater than that which is dictated by the spatial resolution: Ny x Nz x TR.

Other means for k-space sampling have also been developed. One recently described technique is termed "PROPELLER" [5] because of the manner in which a set of vanes is sampled, similar to those comprising a propeller or windmill. The width of each vane may consist of ten or more individual phase encoding views. Because each vane intersects the region in the immediate vicinity of the k-space origin, the redundancy of information potentially allows some immunity to motion artifact as well as the ability to generate a time-resolved image sequence.

Another MR data acquisition technique recently described combines the view sharing of TRICKS, the view ordering of elliptical centric (EC) acquisition [6], and the radial sampling of PR and PROPELLER techniques and uses a star-like pattern to generate a time series of 3D images. The EC-STAR pattern is shown in Figure 3. Each point in the figure corresponds to an individual measurement as sampled in a single repetition of the 3D acquisition. As shown, k-space is divided into three distinct regions: the central disk (R1) and two annular rings (R2 and R3). These regions are sampled at the relative rates of 1, ½ , and ¼, respectively. The time series thereby generated is roughly three times the frequency intrinsic to the sampling. Also, by sampling all of the central views in a group the technique has improved immunity to artifact and reduced latency. This technique has recently been applied to MR imaging in conjunction with continuous table motion [7].

3.2 Parallel Image Reconstruction Techniques

Recently a number of techniques have been described in which the redundancy of information provided from multiple coil elements can be used to reduce the acquisition time for image formation. The two general classes of methods are referred to as "SMASH" [8] and "SENSE" [9]. Here we briefly describe the latter which has thus far been implemented to a wider extent than the former.