Mattes' Mutual Information Metric for Multimodality Registration of DESS and T2 Mapped Knee Articular MR Sequences

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Abstract

Registration of multiple MR sequences remains a challenging problem. The Insight Toolkit (ITK) implements the Mattes' mutual information metric for multimodality registration. Here, example source code, data, and executable files to implement the Mattes' mutual information metric in ITK are provided. Multiple MR sequences of the knee are used as example images. This serves as a companion manuscript for a permanent archive of the source code, executable file and example data and results.

Introduction

There is a growing interest in using quantitative magnetic resonance imaging (qMRI) to identify the degenerative changes of OA in cartilage. One large multi-centered study, the Osteoarthritis Initiative (OAI), has collected qMRI cartilage data using double echo steady state (DESS) and T2 mapping sequences. DESS imaging provides volumetric information while quantitative T2 mapping probes aspects of water content and collagen fiber orientation [1, 2]. In order to access the information contained in the T2 mapping data, there is a need for freely available software to register the T2 maps to higher resolution morphologic sequences, like DESS, on which accurate cartilage segmentation can be performed.

In a typical registration problem, collected pixel intensities are derived from the same type of signal. Metrics in the registration algorithm used to compare the degree of alignment between the image sets can be derived from direct comparison of pixel intensities in corresponding locations of each image. In multimodality registration, such as between DESS and T2 maps, pixel intensities cannot be directly compared because the same anatomic structure on DESS and T2 sequences do not necessarily possess the same pixel intensities. Therefore, a more sophisticated metric is required for multimodality registration, typically a mutual information framework [3, 4]. In this work, Mattes' Mutual Information metric is implemented for multimodality registration [5]. Here, we develop and describe open source software that allows rigid registration of DESS and T2 mapping sequences.

Methods

MRI acquisition: Three-dimensional DESS with water excitation images and T2 mapping images were acquired using sequences approved for the NIH sponsored Osteoarthritis Initiative study [6]. MRI of the knee joint was performed on a 3.0 T Siemens whole body MAGNETOM Trio 3T scanner (Siemens, Erlangen, Germany) using a standard extremity coil. For high-spatial-resolution 3D DESS imaging before registration [2], a total of 160 sections were acquired with a field of view (FOV) of 14 cm (matrix 384x307) with an in-plane spatial resolution of 0.365x0.456 mm and a slice thickness of 0.7 mm with an acquisition time of 11min. For sagittal 2D dual-echo fast spin echo (FSE) sequence for mapping T2 relaxation time, TR was 2700ms and 7 echo images with TE ranging 10-80ms were acquired with matrix of 384x384, in-plane resolution of 0.313x0.313 mm, FOV of 12 cm, acquisition time 11min and slice thickness of 3 mm.

Registration: Multimodality rigid registration of DESS and T2 images were completed using the Mattes' Mutual Information metric across a standard framework (Figure1). The initial description is applied using a deformable model [5]. Here, we assumed the bodies were rigid. The registration software was built using the insight toolkit, a C++ open-source, cross-platform image analysis library (www.itk.org) [7]. DESS sequences were rotated and translated through three-dimensions in the registration process (the “moving” image set) because of their higher and more isotropic resolution as compared to the fixed T2 mapping sequences (the “fixed” image set). Registration between the multiple echo sequences in the multi-echo spin echo (MESE) set was unnecessary as the echo images are not acquired serially but as a single interleaved acquisition. Only the first echo of the MESE set was used for registration since each echo sequence was assumed to be registered to the other echo sequences in the MESE set. In the DICOM header file, the DICOM tag (0018, 0081) was used to extract the first echo image series from the entire MESE set. The tibia and femur were registered simultaneously. Images were transformed through physical space using a three-dimensional rigid verser transform where rotation is represented using a unit quaternion and translated by a vector. During the transform, linear interpolation was used to estimate pixel values during resampling when an exact pixel location on the image grid was not available from the sampled point in physical space (ie. a non-grid position). The registration search space is large, across 6 degrees of freedom. As a result, a specialized gradient decent optimizer is used to define the criterion for the transform parameters to move efficiently through the registration search space. After the transform, the mutual information metric is used to assess the degree of alignment between the two images and the process is repeated until a maximum degree of overlap has been achieved. Parameters were optimized to ensure robustness of accuracy. Registration was completed on a HP590t series computer with a 3.33 mHz Intel core i7-980X six core processor, 24GB SDRAM, 2TB 7200 rpm SATA hard drive, and a Windows 7 64-bit operating system (Hewlett Packard, Pala Alto, CA). After registration, the DESS images were interpolated to contain the same image resolution as the initial T2 mapped images.

Results and Discussion

Here, we describe a strategy to align MRI T2 maps and DESS sequences collected from the same knee using multimodality rigid registration. Multimodality registration allows the segmentation of DESS sequences to be applied to T2 maps. After a DESS sequence has been segmented, the cartilage mask can be applied to the corresponding T2 map sequence. At the bone cartilage interface segmented on DESS images, the non-fat suppressed MESE sequences have a low signal as compared to fat suppressed MESE sequences, referred to as the signal void zone. Multiple post-processing options exist in dealing with extracting quantitative T2 maps using DESS segmentation that contain the signal void zone, including using a threshold between a minimum and maximum physiologic T2 values as a filter. The signal void zone at the subchondral bone interface in these sequences has a thickness of approximately 2 pixels, and can be ignored if it does not significantly alter T2 value calculations.

The accuracy of registration was validated using a checker board layout to visually assess the alignment of the two separate sequences. This accuracy is present throughout the entire three-dimensional sequence (Figure 1). The provided software includes an overlapped checkerboard layout of the image of the two registered images to quickly visually assess registration accuracy on any image set.

Figure Legends

Figure 1. Three-dimensional sagital T2 and DESS sequences before and after multimodality registration of an example patient from the OAI are included (OAI Patient ID 9117692, Left Knee). Overlaid T2 and DESS sequences appear in an alternating checkerboard sequence before and after registration.

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