Inter-image Anatomical Correspondence and Automatic Segmentation of bones by Volumetric Statistical Modelling of knee MRI

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Abstract:
One of the challenging problem in Osteoarthritis is detecting the cartilage loss due to the disease progression. The sensitivity of detection from 3D MR images can be improved significantly by focusing on regions of 'at risk' cartilage has been shown, defined consistently across subjects and time-points. We define these regions in a frame of reference based on the bones, which requires that the bone surfaces are segmented in each image, and that anatomical correspondence is established between these surfaces. Results have shown that this can be achieved automatically using surface-based Active Appearance Models (AAMs) of the bones. In this paper, by building a volumetric (set of surface) appearance model, we are describing a method of refining the segmentations and correspondences with the help of flowcharts and algorithms. We present results from the experiments carried out from this method on MRI knee images using surface AAM which comes out to be more precise for the volumetric AM for the bones than that of the single surface model.

Keywords: *Active Appearance Model (AAM), Active Contour Model, MRI, Search Model, Osteoarthritis, Segmentation.*

I. INTRODUCTION

Segmentation of anatomical objects from large three dimensional (3-D) medical data sets, obtained from routine Magnetic Resonance Imaging (MRI) examinations, for example, represents a necessary yet difficult issue in medical image analysis. With the steady increase of routine use of 3-D imaging methods such as MRI, computer tomography (CT), and 3-D ultrasound in radiological diagnosis, monitoring, radiotherapy, and surgical planning, for example, there is a clear need for improved and efficient methods for the extraction of anatomical structures and for a description by morphometric analysis [1]. In some limited applications, segmentation can be achieved with minimal user interaction by applying simple and efficient image processing methods, which can be applied routinely.

Quantitative analysis of cartilage from high field strength MR images is recognised as a potential biomarker for measuring Osteoarthritis (OA) disease progression and efficacy of disease modifying treatments. OA is a slowly progressing disease and loss of cartilage is difficult to detect over reasonably short timescales. Sensitivity to cartilage loss can be achieved in cohort studies by focusing on 'at risk' regions which are consistent between time-points and across subjects.

In this paper we present an improvement on the surface AAM approach for automatically segmenting the bones and establishing anatomical correspondence between images. The method constructs an Appearance Model of the whole image volume (*Volumetric AM*) which provides a mean reference image and a mapping of correspondence points from the mean image to each of the study images. The volumetric AM approach offers operational advantages compared to the surface AAMs, and possible performance benefits. Unlike the surface AM, the method does not require a training set of manual segmentations of the bones in order to construct the model – just one manual bone segmentation is required, for the mean model image. Identifying the regions of high stress, likely to experience changes in cartilage thickness, is simplified, because reference can be made to the both the mean bone shape and to soft tissue landmarks which are also visible in the mean model image [2].

Our results demonstrate that the volumetric AM provides more accurate segmentations of the bones, as assessed by applying this technique to the set of surfaces obtained from 3d MR images on MRI knee images using surface AAM.

II. METHOD

This section describes an efficient method for generating maps of cartilage thickness and volume for the tibia and the femur. Fig. 1 gives a schematic description of the steps involved in tracking cartilage changes over time.

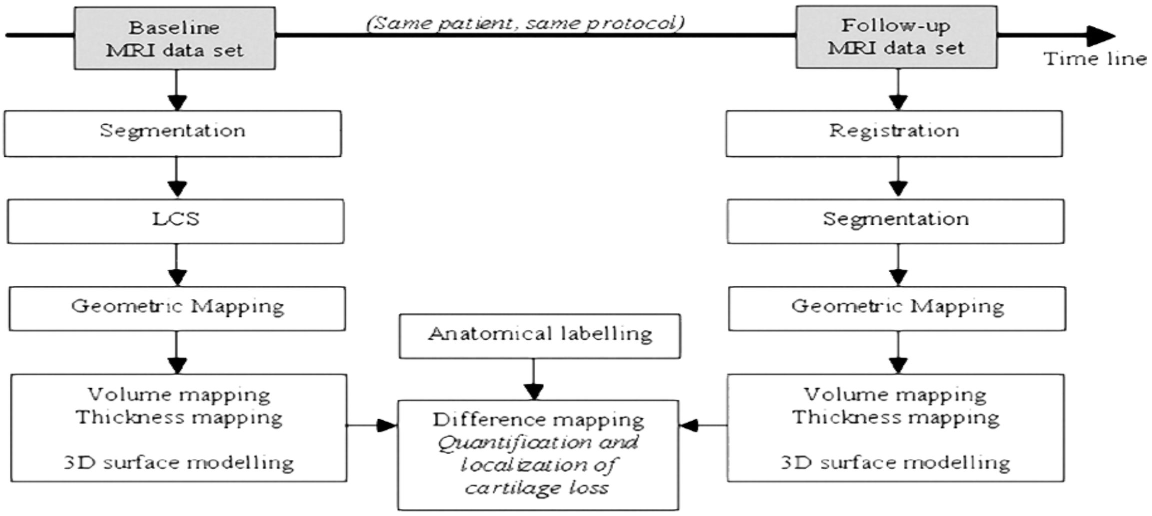

Fig. 1. Schematic Representation

2.1. Active Contour Models

Describe flexible contour models which are attracted to image features. These energy minimizing spline curves are modeled as having stiffness and elasticity and are attracted toward features such as lines and edges. Constraints can be applied to ensure that they remain smooth and to limit the degree to which they can be bent. Snakes can be considered as parameterized models, the parameters being the spline control points. They are usually free to take almost any smooth boundary with few constraints on their overall shapes. The idea of fitting by using image evidence to apply forces to the model and minimizing an energy function is effective.

2.2. Piecewise Linear Image Transformation

A function or operator that takes an image as its input and produces an image as its output. Depending on the transform chosen, the input and output images may appear entirely different and have different interpretations.

2.3. Shape of Model

Make the Shape model, which finds the variations between contours in the training data sets. Computing a shape model from the position of the correspondences in all of the images performing piece-wise affine warping of all of the images to the mean shape and computing a texture model for the registered images computing the best-fit of the shape model to each of the example images and modifying the positions of the correspondences in each example image to minimize the cost of encoding the image using the current model The optimization strategy used three levels of image resolution and employed a course-to-fine regime for manipulating the correspondences at each resolution. The patella, distal femur and proximal tibia bones were segmented in each slice of the mean model image using the End Point software package. In addition, the location of other image landmarks, such as the bones' contact points and extent of the maniacal windows, were marked on the slice segmentations. Closed surface triangular mesh representations of the mean bones were constructed from the parallel slice segmentations providing 60,456 39,238 and 11,808 points on the femur, tibia and patella surfaces respectively. Anatomical regions of interest were drawn on the mean bone shapes using a 3D annotation tool, using both shape and image landmark cues, following the definitions suggested by Eckstein:

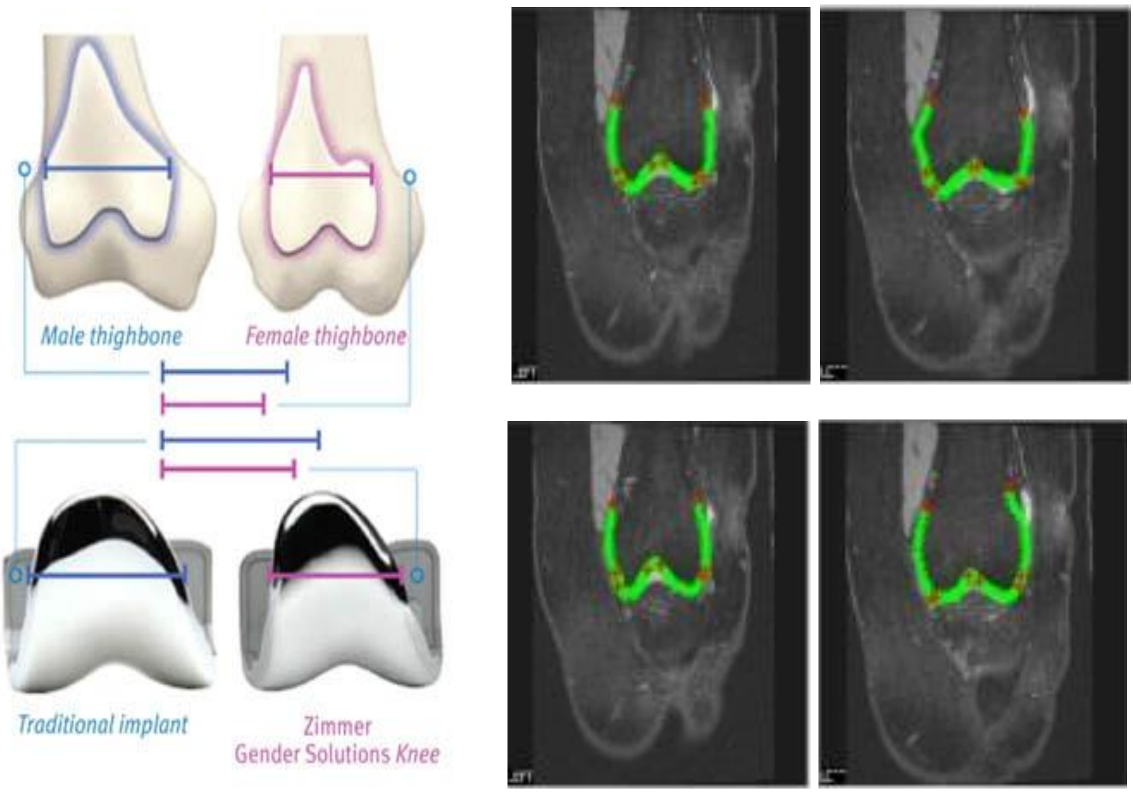

Fig. 2. Shape of the Model

2.4. Search Model

The Search Model is used to find the object location and shape-appearance parameters, in a test set. Training is done by displacing the Model and translation parameters with a known amount, and measuring the error, between the intensities form the real image, and those intensities described by the model.

The found error correlations are used to make the inverse model which gives the optimal parameter update and new location when you input the error vector with difference between model and real intensities.

The objective of knee joint arthroplasty is to eliminate pain and to maintain or restore knee stability and the best possible joint mobility. Until recently, it has often proved difficult to attain these goals, above all to retain them over a long period of time. However, to preserve or restore normal kinematics, the tensioning of the ligaments should be coordinated, and as little bone as possible should be resected; thus, knee joint arthroplasty has become even more elaborate in terms of surgical techniques and requires increasingly sophisticated instruments.

2.5. Combined Model

Often Shape and Texture are correlated in some way. Thus we can use PCA to get a combined Shape-Appearance model.

Principal component analysis (Karhunen-Loeve or Hotelling transform) - PCA belongs to linear transforms based on the statistical techniques. This method provides a powerful tool for data analysis and pattern recognition which is often used in signal and image processing as a technique for data compression, data dimension reduction or their decorrelation as well. There are various algorithms based on multivariate analysis or neural networks that can perform PCA on a given data set. Presented paper introduces PCA as a possible tool in image enhancement and analysis.

Following are the flowcharts (Fig. 3 and Fig. 4) depicting the subdivision process for total area and femoral area of subchondral bone (tAB) and cartilage surface area (AC) in the tibia [3], [4].

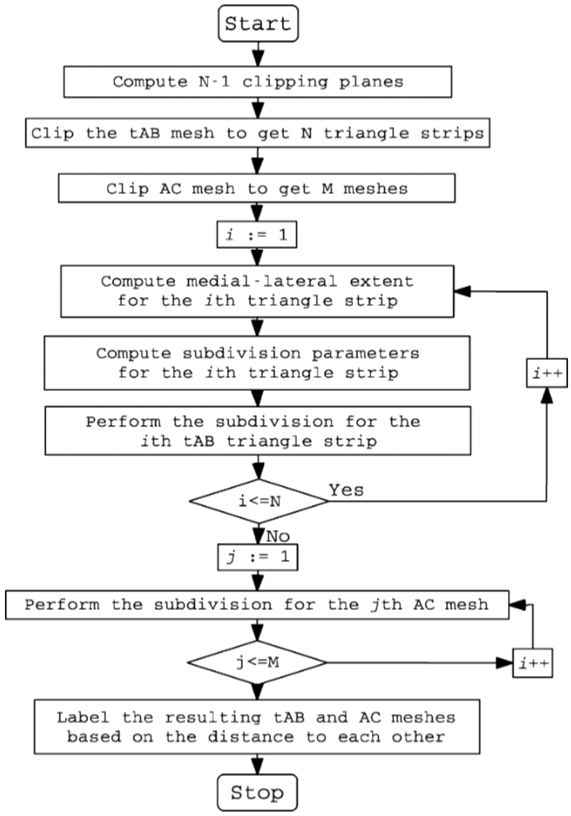

Fig. 3. Flowchart depicting the subdivision process for total area of subchondral bone (tAB) and cartilage surface area (AC) in the tibia.

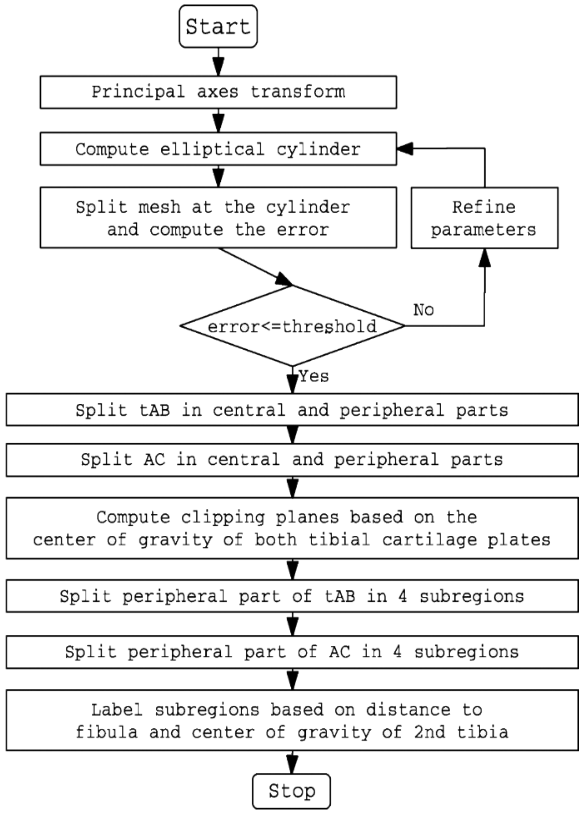

Fig. 4. Flowchart depicting the subdivision process for femoral area of subchondral bone (tAB) and cartilage surface area (AC).

III. RESULTS

The techniques described above were used in application of medical. Here we show results using the Knee models described earlier. Fig. 5 shows the four images which has been used as input. Fig. 6 shows the images for detection of knee bones and after analyzing those images and combining the models we get the concluding results as shown in fig. 7.

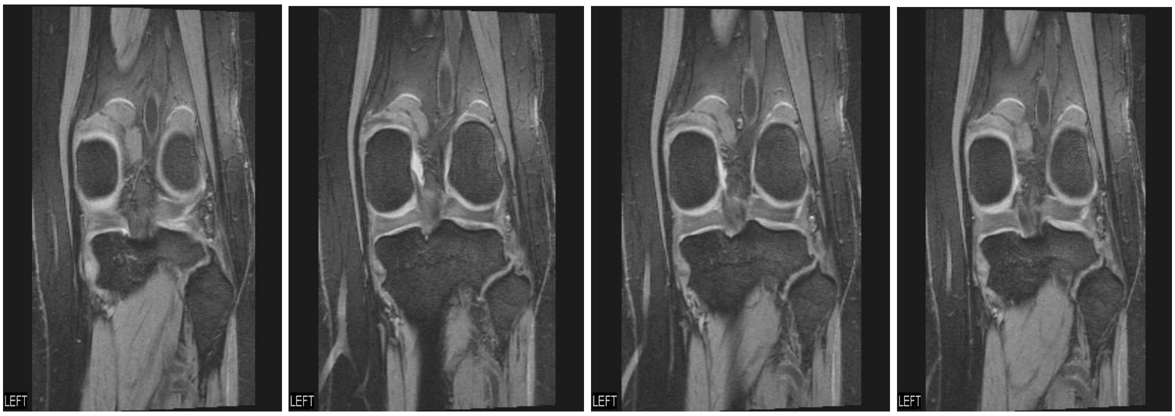

Fig. 5.

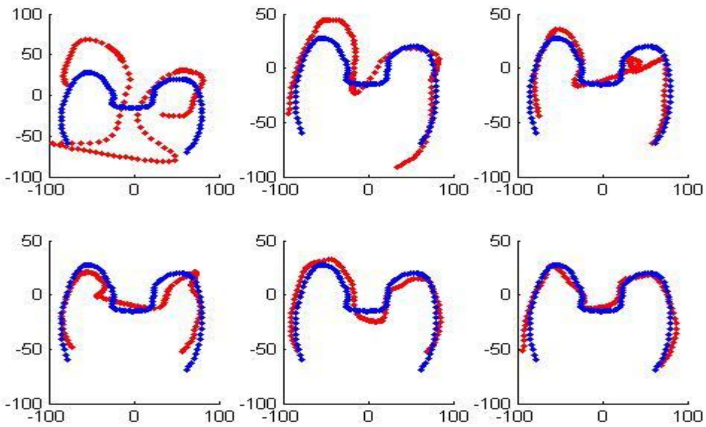

Fig. 6.

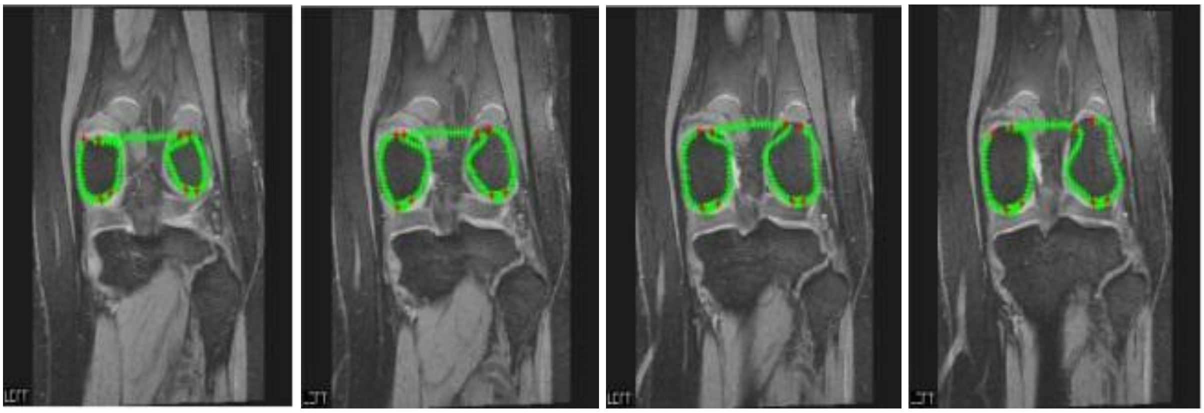

Fig. 7.

IV. CONCLUSION

In this paper we described the construction of a volumetric AM to refine the inter-image correspondence provided by surface AAMs. Finding and describing the object in a test image, using the multi scale model. We start with the mean shape on the location, and use the search model to find the Knee location, shape and appearance.

The results demonstrate that the volumetric AM approach improves the accuracy of the bone segmentations, compared to the surface AAM. Moreover, the volumetric AM also provides robustness and is able to segment smaller structures, such as the patella bone, which was not possible using the surface-based AAM approach. This is due to the volumetric AM's ability to locate the patella in relation to the other structures within the image. Results on reproducibility of regional mean thickness measures indicate that the volumetric AM provides better intra-subject reproducibility across multiple images, indicating that longitudinal measures of change in cartilage thickness are likely to be more sensitive.

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