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SEGMENTATION OF ACL IN MR IMAGES

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Abstract: ***Knee joint is the largest anatomical joint within the human body which facilitates the ease of movement from one place to another. Knees are most complex and delicate joints. Knee joints are frequently injured and damaged due to articulations. The knees are among the joints most commonly affected by osteoarthritis (OA). The pathophysiology of osteoarthritis (OA), a common debilitating disease afflicting over 71 million people globally, is poorly understood and a treatment to slow, halt, or reverse the disease progression remains elusive. Among the ligaments responsible in maintaining the structural integrity of knee joint, anterior cruciate ligament (ACL) injury is most commonly diagnosed. Recent advancement in clinical imaging technology has led to wide employment of magnetic resonance imaging (MRI) in such injury assessment.***

In this paper, a semiautomatic ACL Segmentation program implemented in MATLAB is proposed. It takes advantage of the ACL's unique shape and orientation within MR images to carry out the segmentation. The goal of medical image segmentation is to partition a medical image in to separate regions, usually anatomic structures that are meaningful for a specific task. In many medical applications, such as diagnosis, surgery planning, and radiation treatment planning determining of the volume and position of an anatomic structure is required and plays a critical role in the treatment outcome.

Keywords: ACL, Knee, MRI, Osteoarthritis, Segmentation.

1. Introduction

1.1 Medical Image Segmentation

Image segmentation is subdividing an image in to its constituent regions or objects. The level to which the subdivision is done depends on which application or problem we are solving. The main goal of image segmentation is domain independent partitioning of an image into a set of disjoint regions that are visually different, homogeneous and meaningful with respect to some characteristics or computed properties, such as grey level, texture or color to enable easy image analysis (object identification, classification and processing).

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As the development of modern imaging modalities such as magnetic resonance imaging (MRI) and computed tomography (CT), physicians and technicians nowadays have to process the increasing number and size of medical images. Segmentation is usually a necessary step for the task. Therefore, efficient and accurate computational segmentation algorithms become necessary to extract the desired information from these large data sets. Moreover, sophisticated segmentation algorithms can help the physicians delineate better the anatomical structures presented in the input images, enhance the accuracy of medical diagnosis and facilitate the best treatment planning and prior knowledge like the imaging procedure or the biomechanical behaviors of organs or structures can be crucial for a successful segmentation.

Magnetic Resonance Imaging uses magnetization and radio waves, rather than x-rays to make very detailed, cross-sectional pictures of the anatomical structures. It has many advantages over conventional imaging techniques. Few of them are

- High spatial resolution
- Excellent discrimination of soft tissues
- Rich information about anatomical structure.

1.2 Anterior Cruciate Ligament Segmentation

Knee joint is the largest anatomical joint within the human body [1] which facilitates the ease of movement from one place to another. Although it can withstand up to 24 times the bodyweight of a human [2], it is also most vulnerable to injuries

[1] as a consequence to its structural instability that provides the much required mobility.

Among the ligaments responsible in maintaining the structural integrity of knee joint, anterior cruciate ligament (ACL) injury is most commonly diagnosed [3]. In the past, clinical diagnosis such as anterior drawer test and Lachman test were used to assess such injury [4]. However, with recent advancement in clinical imaging technology, magnetic resonance imaging (MRI) is now widely employed as a complement with such diagnosis to improve the assessment accuracy [5]. This is because MRI is the only imaging modality that allows direct non-invasive evaluation of soft tissue without contrast agents [6]. In addition, it uses a non-ionizing source for imaging purposes and thus does not compromise the safety of patients [7].

With the widespread utilization of MRI, large volume of images per imaging session has resulted with much tediousness and time consuming image analysis [8]. This is because the qualitative visual assessment of ACL injury severity often requires a radiologist to manually trace the boundaries of interested structures using computer software [9] (e.g. presurgical preparation and post-operative diagnosis). Although such interpretations of MR images by most radiologists provide a reasonable accuracy of 89.47 % [10], it is often subjective with possible errors and biasness as it is based on one's opinion and past experiences. Thus, the clinical diagnosis made is often subjected to both inter- and intra-observer variability [11] with a variation coefficient of 5 % or more for repeated tracings by a single observer [12].

The aim of this project is to formulate a program that performs semi-automatic ACL segmentation on MR images sing morphological operations with active contour. The main motivation is to reduce the amount of time spend in image analysis while providing a more reproducible and objective assessment with regard to ACL injury severity.

2. MATERIALS AND METHODS

2.1 MR Images and Manual Segmentation

For this study, a population of four volunteers ranging in age from 30 to 35 years (average age: 33 years) with no previous history of knee traumas were involved. Four sets of isotropic proton density weighted images of knee joints on sagittal plane were acquired using a Siemens Magnetom Verio 3T MRI scanner with a lower extremity knee coil. Each set corresponded to either the right or left knee of a volunteer and consisted 192 images. The images were acquired according to the following parameters: spin echo (SE) imaging sequence with repetition time (TR) of 1300 ms, echo time (TE) of 38 ms, field of view 150 cm x 150 cm, matrix size 320 x 320, slice thickness 0.5 mm. It is important to state here that among the four acquired sets of MR images; only set 1 has a matrix size of 520 x 520.

The MR images were assessed by a radiologist who is experienced in musculoskeletal MR imaging. All knee joints displayed in the images were deemed anatomically normal with no abnormalities found. Manual segmentation of ACL was carried out on all four sets of images using a custom-built program that was written in MATLAB. The segmented results were evaluated by the radiologist to ensure that the ACLs were correctly traced.

2.2 Proposed Semi-Automatic ACL Segmentation

The proposed semi-automatic ACL segmentation program is implemented using MATLAB and according to the methodology illustrated in Figure1. A summary of this program flow is described as bellow.

At the start of the program, the user is prompted to specify the number of images present within the image set that is to be segmented. Data of the first image within the set is read and duplicated. The duplicated image undergoes a pre-processing procedure that comprises steps 3 to 4 of Fig. 1. During this process, gamma transformation is first applied to the image to suppress the low intensity features while amplifying the differences of features with high intensity values.

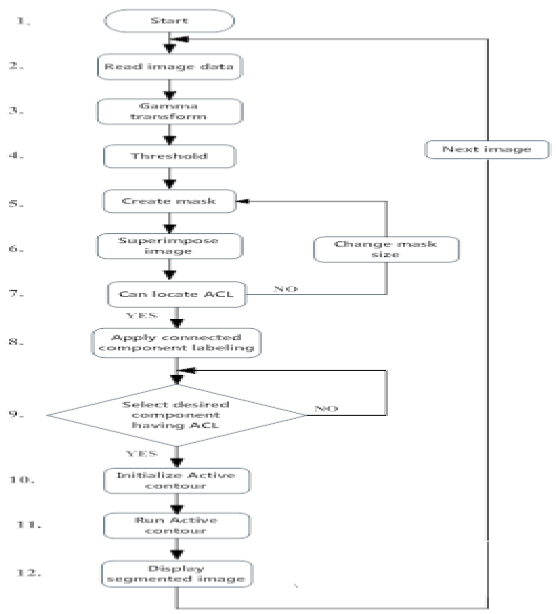

Figure 1: Proposed methodology of semi-automatic ACL segmentation.

This is to improve the contrast of ACL relative to its surrounding features since it tends to appear as a homogenous low intensity feature in MR images [13]. Thresholding is then performed using Otsu's method to convert the resultant into a binary image. By utilizing the femur and tibia as references, a predefined cropping mask as displayed in Figure 3.2 is used with morphological operations to crop the binary image. Thus, only features surrounding the ACL remained as in steps 5 to 7.

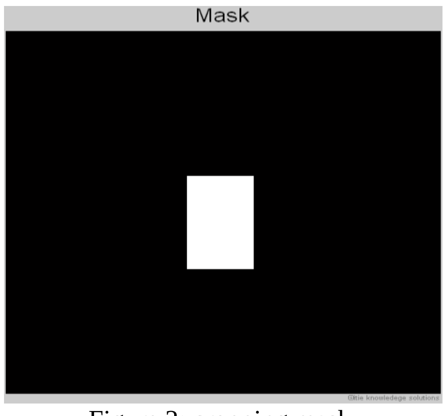

Figure 2: cropping mask.

In order to improve the segmentation accuracy, connected components labeling and selection of component by user carried out in steps 8 to 9 as illustrated in Figure.3.1. This involves the use of additional morphological operations to further remove undesirable features.

Finally in steps 10 to 11, the achieved image is used as an initialization mask for the application of an active contour onto its corresponding original image. The principle of this hybrid active contour is based on a paper by Kaihua Zhang [14], which is a hybrid level set active contour which is implemented special processing named Selective Binary and Gaussian Filtering Regularized Level Set (SBGFRLS) method. This active contour is ideal for the present study since it does not rely on edge information and can detect objects whose boundaries are not necessarily defined by gradient. Hence, these characteristics ensure that a good ACL segmentation is obtainable.

3. RESULT AND ANALYSIS

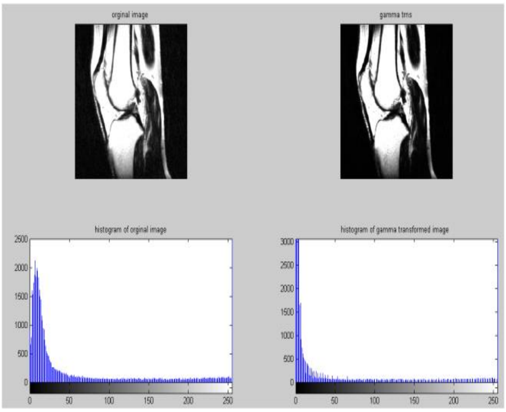

Figure 3: Original and gamma transformed images.

In Figure 3 the original Knee MR image and Gamma transformed image with their histogram is shown. The histogram difference can be observed with its intensity values shifting to words left so the image enhancement can be observed in gamma transferred image.

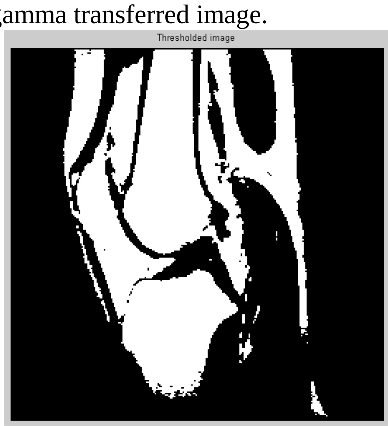

Figure 4: Threshold image.

In Figure 4 the Threshold image of enhanced image is shown. This is nothing but a binary image in which the original enhanced image data is retained. This helps in further processing without losing original data.

In Figure 5 the masked image of ACL is shown. This is achieved by using cropping mask shown in Figure 2.This helps for selecting region of interest.

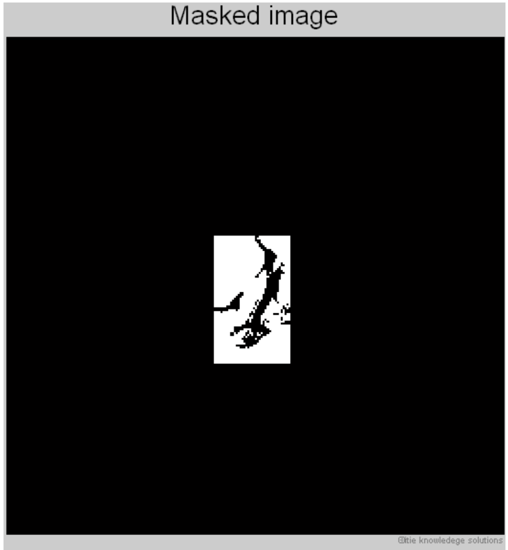

Figure 5: Masked image.

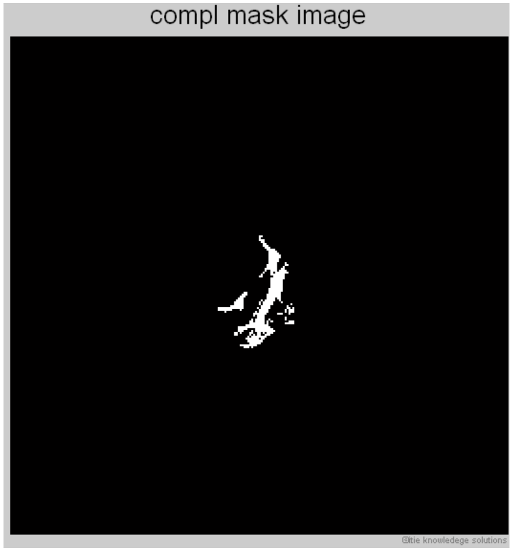

Figure 6: Complement of Masked image.

Figure 7: Image showing segmented ACL

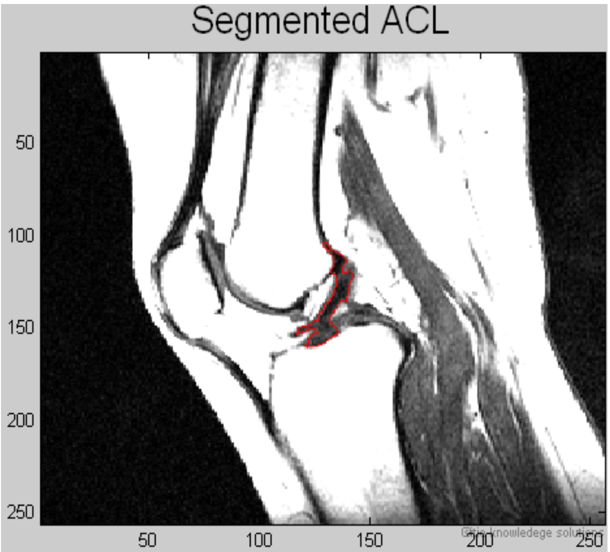

Figure 8: Image showing segmented ACL

In Figure 8 Segmented ACL is shown with clear separation with other Knee bones and muscles.

4. CONCLUSION

In this paper, A program that allowed semi-automatic ACL segmentation in MR images had been developed. This program utilized morphological operations, connected component labeling and hybrid level set active contour, while taking advantage of the ACL's unique shape and orientation within image.

Although much improvement is still necessary before this program can be deployed for clinical image diagnosis, this study had proven its feasibility and potential in providing an objective ACL segmentation with high reproducibility.

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