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Research on 3D Reconstruction Method ACL-based

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Abstract

Anterior cruciate ligament (ACL) 3D reconstruction is a challenging problem for both orthopedic and sports surgeons. In this paper, to investigate the method of quickly establishing 3D digital model of ACL using 2D magnetic resonance images (MRI) and 2D computed tomography (CT) images, we propose an new scene-based segmentation 3D reconstruction method for anterior cruciate ligament. First, CCD camera is anglicized for 3D reconstruction method. Second, scene segmentation method is proposed to get image patch set. Third, the distance is calculated between the image patch and viewpoint of CCD camera. Finally, the proposed method is done for scene reconstruction. The performance of the proposed model is demonstrated on various 2D MRI and CT images. A relatively reliable ACL 3D reconstruction results indicate the validity of our method. The proposed method can provide a complete set of computer aided ACL operation system and realizing the individualized anatomical reconstruction of ACL.

***Keywords**: 3D Reconstruction, Anterior Cruciate Ligament, Scene segmentation*

1. Introduction

The anterior cruciate ligament is one of the major construct of stabilizers of the knee. ACL ruptures are frequent injuries, mainly occurring in sports and fitness activities. Anterior cruciate ligament in juries affect more than 175,000 patients annually [1]. Located in the center of the knee joint, the ACL is the major stabilizing ligament of the knee. If the ACL is injured, then the knee becomes unstable and can buckle when the person pivots. Surgeons can use autograft or allograft tissue to accomplish ACL reconstruction by using a single bundle or double bundle type of repair.

The surgeon performs the reconstruction arthro scopically, using two ports and a small incision over the anteromedial surface of the tibia to facilitate passage of the graft and for distal fixation of the graft. Correct placement of the tibia and femoral tunnels is the most important technical aspect of ACL procedure [2]. After reconstruction, the patient must undergo intense physical therapy starting one or two days after surgery. The goal of ACL reconstruction is to return the patient to a previous level of function while preventing later degeneration of the knee. Although single/double-bundle reconstruction is widely used for ACL reconstruction, recent researched results have shown that reconstruction of both bundles (AM and PL) may better re-establish the normal kina matics of the knee [2]. Thus, there is still room for continued improvement in ACL reconstruction.

In order to overcome these limitations of researcher’s mentions, we propose a scene-based segmentation approach for ACL reconstruction with complicated scenes. In next section, we discuss the related work of ACL reconstruction, then, the proposed framework for ACL 3D reconstruction is described in Section 3, experimental results are shown in Section 4. We also give conclusion in Section 5.

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2. Related Work

The ACL comprises two separate functional boundless named for their tibia insertion sites: the anteromedial bundle (AMB) and the posterolateral bundle (PLB). The detailed description sees Figure1. Both bundles are evident during fetal development and persist throughout life.

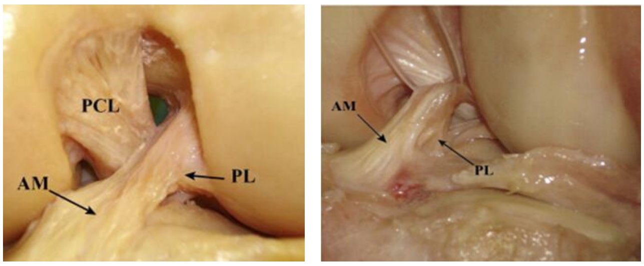


Figure 1. Cadaveric Dissection Showing the ACL and its Two Distinct Bundles (AMB And PLB) from the Medial (Left) and Lateral Viewpoint (Right) [10]

AMB and PLB's accurate location is vitally important for successful reconstruction surgery and subsequent knee rehabilitation. However, accurate ACL reconstruction has some limitations as follows [3-4]: (1) Do not get accurate location of the angle, length, and width of the footprint. (2) The difference between the placement of ACL reconstruction tunnels and the insertion of the healthy ACL in patients. (3) The double bundle measurement uses the different approaches and tools.

3D computer model of the knee is constructed from the scan's images. Recently, a new 3D classification system at hospital is developed, in which reference axes are embedded on the tibia and femur of each knee. The traditional ACL reconstruction method includes the anatomical double bundle ACL reconstruction technique, the anatomical single bundle ACL reconstruction technique, and ultrashort echo-time technique [5]. The anatomical double bundle ACL reconstruction technique depend on accurate location of AMB and PLB, the footprint angle, and the distance from the footprint edge to the margin of the articular cartilage vary from individual to individual[6]. The other disadvantage is that the anatomical double bundle ACL reconstruction procedure involves the difficulty of the technique, subsequently long operation time, economically high cost and the dyes function of the two reconstructed bundles [7]. The single bundle ACL reconstruction by understanding insertion site anatomy and sizes, the surgeon will realize tailors the tunnel size. Meanwhile the method matches the tunnel position on femoral and tibia insertion sites. It will more consistently restore the anatomy of the native ACL [8]. To evaluate knee stability after double bundle and single bundle of ACL reconstruction, Shi *et al.* [9] used randomized controlled trials and quasi-randomized controlled trials from MEDLINE. All experimental data are performed with the Cochrane collaboration's Revman 4.2.10 software. Experimental results show that the double bundle ACL is superior to single bundle ACL in terms of anterior stability and rotational stability. The limitations is that all experimental datum is small and of poor quality. The more high quality and large scale randomized controlled trials should be required for further evaluation.

Ultrashort echo-time technique can visualize components in ligaments [10-12]. 3D UTE techniques yield isotropic spatial resolution, allowing for easy data reformatting following the course of the graft through the knee anatomy. Thus, UTE imaging may deliver additional information about the condition of the tendon graft and its fixation. However, only the acquisition software was modified to facilitate UTE sampling and online reconstruction of 3D radial image data [13]. This is crucial for the potential integration of UTE scans into future clinical protocols for purpose of evaluation of the described contrast. Such as knee MRI after ligament repair.

3. The Proposed Algorithm

The detailed procedures of the proposed method can be described as in Figure2. The proposed method for ACL 3D reconstruction is composed of the following four components: (1) CCD camera analysis, (2) scene segmentation, (3) step calculation, and (4) image patch reconstruction. These steps are described in details in the following.

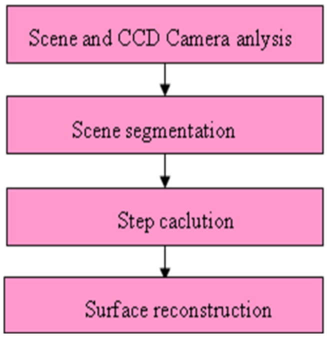


Figure 2. A Block Diagram of the Proposed ACL 3D Reconstruction Method

3.1 CCD Camera Analysis

In this paper, CCD camera viewpoint is set point $V(X_v, Y_v, Z_v)$, an arbitrary location of image surface is set point $P(X_{up}, Y_{vp}, Z_{1p})$ .The relationship between camera viewpoint and its image surface can be described as follows.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} \alpha & 0 & u_0 \\ 0 & \beta & v_0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} * \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} \tag{1}$$

where α and β is the scale factors of u and v axes in image surface. R and t are the extrinsic parameters of the vision system, which express the rotation and translation from the world coordinate system (X_w, Y_w, Z_w) to the CCD camera coordinate system[14]. Image zoom depends on CCD position. In our work, we added zoom coefficient k based on vector u and v, which is described as follows:

$$\begin{bmatrix} u' \\ v' \end{bmatrix} = \begin{bmatrix} ku \\ kv \end{bmatrix} * \begin{bmatrix} R & t \\ 0^T & 1 \end{bmatrix} \tag{2}$$

3.2. Scene Segmentation

3D reconstruction scene (S) of ACL is segmented n image surface $S_{f1}, S_{f2}, \ldots S_{fi} \ldots S_{fn}$ ($i = 1 \ldots\ldots n$). And then it satisfies condition as follows:

$$S = S_{f1} \cup S_{f2} \cup \ldots S_{fi} \cup \ldots S_{fn} \tag{3}$$

Note that, (1) 3D reconstruction scene S includes scene and CCD camera. (2) All image surface must visible as order, for example, if image surface S_{f1} shelter image surface S_{f2}, image surface S_{f1} will be reconstructed than image surface S_{f2} firstly.

Meanwhile, scene segmentation must satisfy two basic conditions as follows:

(1)Scene S satisfy consistent with each other. Complete scene S has:

$$color(p, S_{fi}) = color(S(p), S_{fi}) \tag{4}$$

$$\forall p \in S_{fi}, \forall S_{fi} \in \{S_{f1}, S_{f2}, \cdots S_{fn}\} \tag{5}$$

Here, P is pixels. Scene S and image surface $S_{f1}, S_{f2}, \ldots S_{fn}$ is consistent. All image patch set can be expression to 3D model by pixels. The image patch set is described as follows.

$$\bar{s}_{fi} = \{S_{f1} \mid p \in S_{fi}, 1 < i < n\} \tag{6}$$

(2)Valid image patch set. All input scene S_i is satisfy condition $p \in f_i$, $q \in f_j$ image patch set $S_f = \bar{S}_{fi}(p) = \bar{S}_{fj}(q)$.

So,

$$color(p, \bar{S}_{fi}) = color(q, \bar{S}_{fj}) = color(S_f, \bar{S}_{fi}) \tag{7}$$

Here, if satisfy Eq. (7), an image patch set $\bar{S}_{fi}$ is valid patch set.

(3) Image patch consistent. All valid image patches $\bar{S}_{fi}$ has:

$$color(p, \bar{S}_{fi}) = color(S_f(p), \bar{S}_{fi}) \tag{8}$$

$$\forall p \in \bar{S}_{fi}, \forall S_{fi} \in \bar{S}_{fi} \tag{9}$$

3.3. Step Calculation

Suppose the distance between the image patch and viewpoint of CCD camera is set d. Camera view angle is set θ. The length and wide of project max area is set h and w. The length and wide of project image is set h_i and w_i, then h and w can be get by.

$$\begin{cases} w = \tan(\theta/3) \times d \times 2 \\ h = w \times h_i / w_i \end{cases} \tag{10}$$

Note that, the size of image patch decides the related pixels of image patch. If image patch have more pixels, projected results include massive pixels, reconstruction accurate of ACL do not detailed well. In this paper, we use the distance from image patch to viewpoint of CCD camera to adjust step length. Two steps length (vertical StepX and horizontal to StepY) of image patch can be calculated as follows:

$$\begin{cases} StepX = w / h_i \\ StepY = h / w_i \end{cases} \tag{11}$$

3.4. Image Patch Reconstruction

Image patch $\bar{S}_{fi}$ include the different number of the slices S_{sfi}, here $i = 1 \ldots k$. The detailed step of the proposed method is shown as follows:

Algorithm1: ACL reconstruction method based on sence segmentation

Input: image patch $\bar{S}_{fi}$ with k slices each patch.
Procedure:

Step1: for an image patch $\bar{S}_{fi}$, $\bar{S}_{f1} = \{\bar{S}_{sfi} / \bar{S}_{sfi} \in F_{sf}^d\}$ here, $F_{sf}^d = \{\|f\|_{sf} = d\}$, all the slices of an image patch will be included in image patch.

Step2: for an image surface S_{fi}, $\bar{S}_{f1} = \{\bar{S}_{sfi} / \bar{S}_{sfi} \in F_{sf}^d \cup S\}$ all the slices of an image patch will be projected, all projection images must pixels color of consistency with scene S.

Step3: for an slice S_{sfi} ($i=1...k$), S_{sf1} will be in initialized to empty, then, mean square deviation l of the slice will be computed, if l is less than threshold th, the slice will be added to image patch $\overline{S}_{fi}$.

Step4: repeat step3, until all the slices be added to image surface S_{fi}.

Step5: repeat steps1-4, until the entire image patch $\overline{S}_{fi}$ be reconstructed to 3D reconstruction scene S.

4. Experimental Results

In this section, in order to demonstrate the performance of the proposed method, we show experimental results for our proposed scene-based segmentation 3D reconstruction method. The experiments are performed in Pentium (R) Dual-Core 3.06 GHz, eight core computers with 16GB DDR3 memory. All experiments are implemented using Visual C++ programming language. Figures (4, 6, 7) include all cohere tissue of ACL.

Due to image surface isotropic spatial resolution, in our work, the 3D data acquisition approach chosen is not only beneficial, but it is also advantageous with respect to signal-to-noise ratio. We scans the magnetic resonance imaging (MRI) from 100 consecutive patients and 188 knees, here, 94 without osteoarthritis and 94 knees with osteoarthritis. Figure3 shows 2D MRI images.

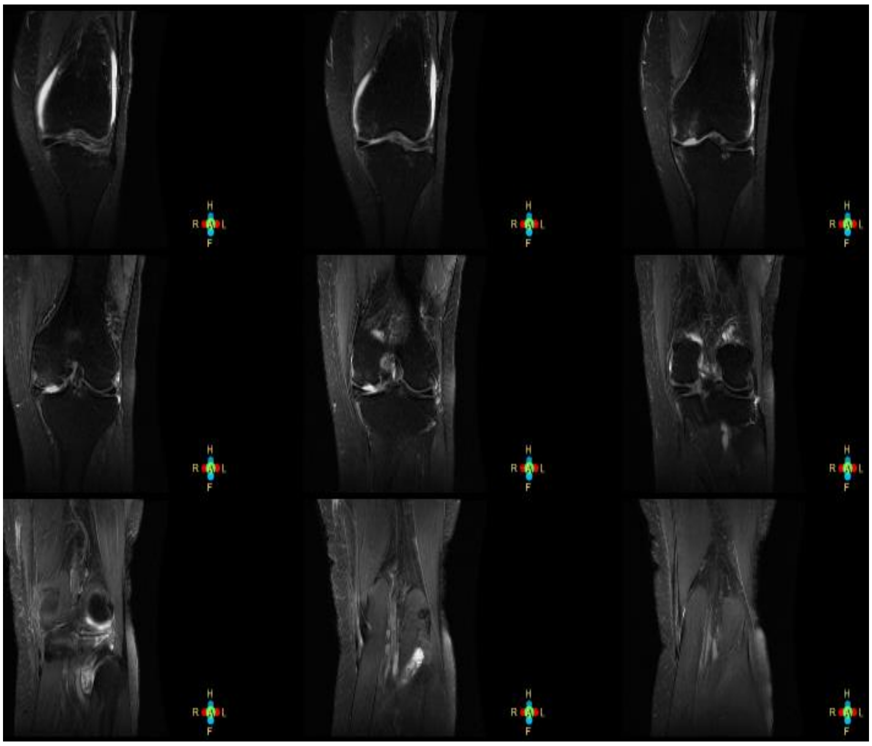


Figure 3. 2D MRI Images, H, A, P, F Denote Rotated Direction

Due to limited space, only some of the samples are chosen to be shown in this paper. In order to demonstrate the performance of the proposed method well, Figure4 shows a complete experimental processing and the results of scene-based segmentation 3D reconstruction method for ACL. From Figure4, it show robustness of the proposed method well and overcomes the drawbacks of the traditional methods.

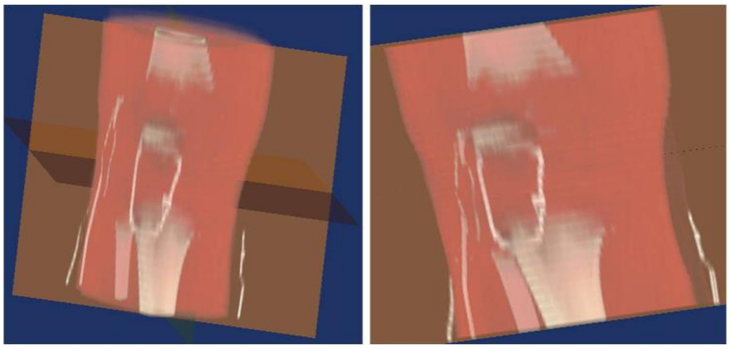


Figure 4. The Results of ACL Reconstruction of Using our Method. Note that: here Include all Cohere Tissue of ACL

In order to show robustness of our method, our method also use 2D computed tomography (CT) images, which include 30 consecutive patients and 42 knees(22 without osteoarthritis and 20 knees with osteoarthritis.). Figure5 shows 2D CT images, which include four direction (left, right, front, bottom, top, and back) of each image surface. Figure6 shows 3D reconstracted results of ACL. From Figure6, it show the proposed method can fit 2D CT images for ACL.

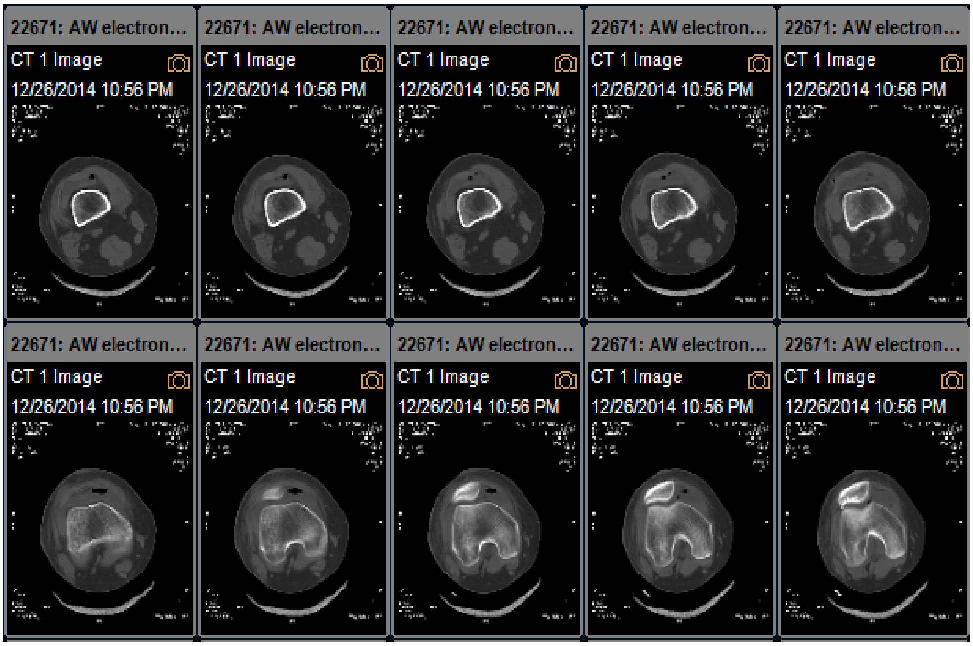


Figure 5. 2D CT Images

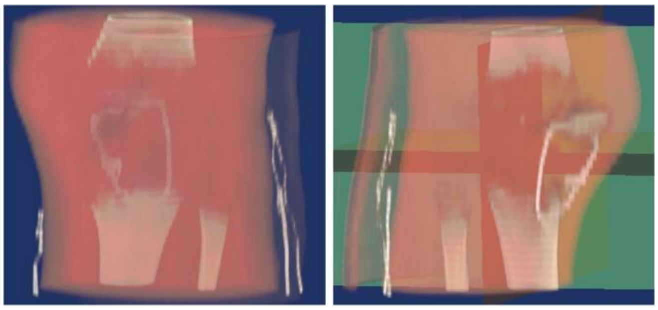
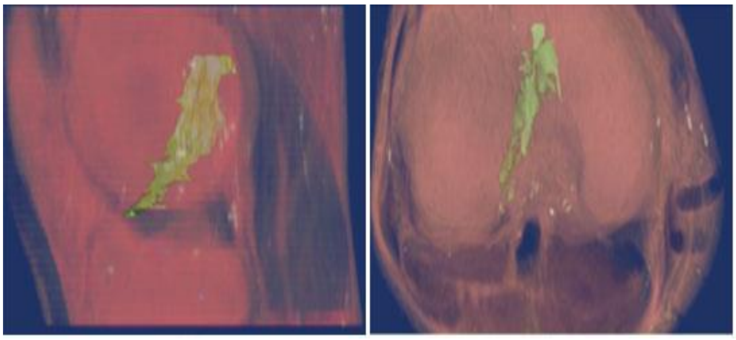


Figure 6. ACL Reconstruction of our Proposed Method using 2D CT Images. Note that: here Include all Cohere Tissue of ACL

Due to the poor/complex background image quality of the worn parts in actual application situation, a series of filter algorithms are carried out to remove the noises of the captured images surface. The outcome of ACL reconstruction using the proposed method in combination with extra-articular tenodesis is satisfactory in the very long term, in knees with a preserved medial meniscus. Figure7 shows ACL reconstruction results.



(a) (b)

Figure 7. Experimental Results using the Proposed Method for ACL (a) ACL Reconstruction using MRI Images, (b) ACL Reconstruction using CT Images Note that: here Include all Cohere Tissue of ACL

5. Conclusions

In this paper, we propose an effective ACL reconstruction approach. In our study, the proposed method is used to reconstruct ACL the patients, which had sport related injury. Experiment part, 2D MRI and CT images is adapted for reconstrction. The reconstrcted results were satisfied with their results.

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