Deriving a 3D Femur from Multiple Radiographs

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ABSTRACT

A Femoral Acetabular Impingement refers to a pathological condition where deformities of the hip bones deteriorate the joint's protective soft tissues. Unfortunately, the two primary imaging methods used to diagnose this condition (CT and X-Rays) both have major drawbacks. This paper describes on-going research towards a hybrid approach to eliminate these drawbacks by synthesizing CT-like results of the hip-bones by using multiple x-ray images as input. To accomplish this, Digitally Reconstructed Radiographs are used to create a mapping between the two imaging methods and Principle Component Analysis is used to express the variety of shapes for 3D femurs.

KEYWORDS: Femoral acetabular impingement, digitally reconstructed radiographs, computed tomography, radiographs.

INDEX TERMS: J.3 [Life and Medical Sciences]: Health; I.4.5 [Image Processing and Computer Vision]: Reconstruction—Transform Methods

1 INTRODUCTION

A healthy hip functions much like a ball-and-socket joint composed of two contact bones. These bones are the femur and acetabulum, located in leg and hip respectively. Hip motion is facilitated by layers of soft tissue between these two bones, such as the articular cartilage which covers the contact surfaces and the labrum which seals the hip joint.

A Femoral Acetabular Impingement (FAI) describes a pathological condition where there exists a bony bump-like deformity on either the femur's head (ball) and/or the acetabular rim (socket) which causes abnormal contact between the two bones during normal hip flexion. If this condition is left untreated, the joint's integrity will degrade over time due to increased damage to the soft tissue. FAIs have been associated with the development of cartilage damage, labral tears, early hip arthritis and lower back pain, among other complications. As such, quickly identifying and treating a patient suffering from a FAI reduces the likelihood of irreversible damage being incurred[1].

Physicians typically have two primary sources they can examine for diagnosing FAIs: (1) radiographs (x-rays images), (2) Computed Tomographic (CT) volumes. Unfortunately, both these sources have weaknesses to balance out their strengths. CT scans provide physicians with a 3D view of a patient's pelvis, thus no details of patient's hip can be obscured. However the CT machines themselves are quite large, expensive and can have a waiting period of three or more months for a scan. On the other hand, x-ray machines have a lower cost, higher availability and lower radiation exposure compared to CT machines. Conversely, radiographs suffer from having a single view and flattened details.

The goal of this research is to supply physicians with a new diagnostic tool that uses two or more pelvic radiographs as input and in return provides a 3D approximation of the femur and acetabulum. The advantage of this hybrid approach is to combine the specific strengths of the CT and radiographic imaging methods without carrying over their disadvantages.

Related work aimed at achieving the same goal tends to use parametric models to express the variety of femur shapes. One such approach used by Baudoin et al.[2] was to use parameters such as the femoral head radius, neck shaft angle, neck length, etc. to describe a 3D femur's form and orientation. Alternatively, Kurazumea et al.[3] generated their 3D femur from parameters obtained through Principle Component Analysis (PCA) of polygonized segmentations of CT data. What differentiates our research from similar work is that (a) our parametric models are generated from CT voxel intensity values and (b) our data set includes patients diagnosed with FAIs.

2 METHODOLOGY

The following subsections provide a brief overview of the currently implemented and forthcoming steps required to accomplish this research's goal. To begin with, this research has concentrated on recreating the femoral head only as an experiment to validate the intended methodology before recreating CT-like results for whole femurs and acetabulums.

2.1 Segmentation

The data-set used in this research originates from 20 patients, 17 of which were suffering from FAI in at least one hip at the data's time of taking and 3 from a control group. For each patient there is one pelvic CT scan, one digital radiograph taken from the patient's front and another taken from the patient's right.

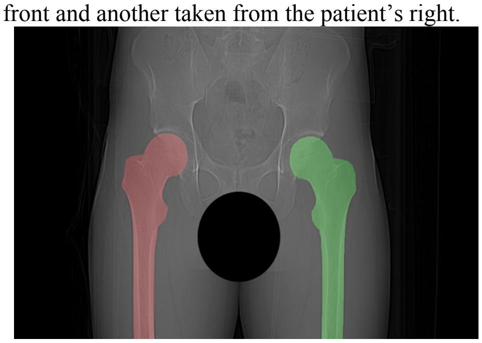

Figure 1. Segmented frontal radiograph. Pixels belonging to the patient's right/left femur are colored in red/green

Before this data can be interpreted, its relevant features had to first be segmented for extraction. Specifically, the pixels in the radiographic images and the voxels from the CT scans were labelled as belonging to the right femur, belonging to the left femur, belonging to both femurs or belonging to neither. Figure 1 shows an example of the pixels in a frontal radiograph that would be labelled as belonging to femurs. All segmentations were done semi-automatically using an in-house program and then corrected manually to eliminate possible machine errors.

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2.2 Digitally Reconstructed Radiographs

In order to create CT-like shapes from radiographs, a mapping scheme must be established between the 2D and 3D segmented objects. To accomplish this mapping, Digitally Reconstructed Radiographs (DRRs) are used. DRRs describe a number of volume rendering approaches which attempt to generate synthetic radiographs from CT data. In this research, DRRs are used to provide a flattened view at various angles of a CT volume. The femoral contours from these flattened views can be compared to those found on the corresponding radiographs. These overlapping contours (as well as their interiors) can be used to provide the necessary mapping.

Of the many approaches available for generating DRRs, raycasting is considered the standard[4] because it returns the highest fidelity results. As such, a raycasting scheme was adopted for this project and implemented to exploit the latest graphics hardware in order to offset its associated high computational cost. This scheme naturally lends itself to simulating the radiographic process inside a 3D graphics environment:

1. A point in space is chosen to represent the source of x-rays
2. The location of the radiographic plate is replaced with a similarly sized texture
3. For each pixel on the texture, a ray is cast from the point in space to that pixel
4. If a ray traverses the CT volume, the pixel associated with the ray accumulates the intensity values of all the voxels touched by the ray
5. The resulting texture is the DRR

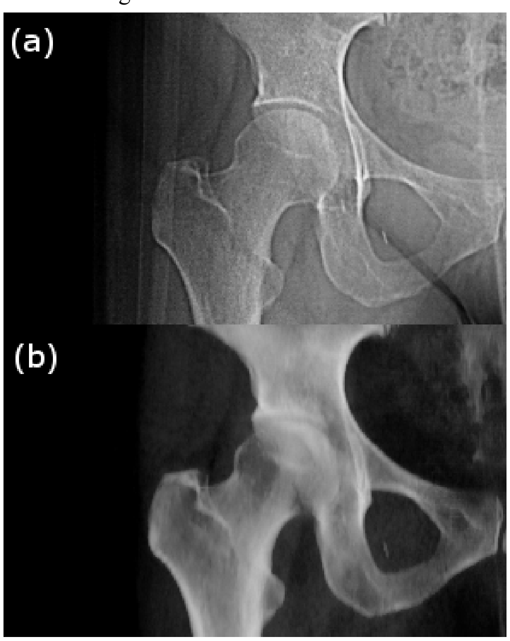

Figure 2. (a) Radiograph of a patient's femoral head (b) DRR of the same patient's femoral head with soft tissue subtracted

An additional complication exists in that CT data is captured using a different process than radiographs which results in there being a registration error between the DRRs and the radiographs along the patient's vertical axis. This is caused by a CT scan's slice-based approach, which is different from capturing the whole volume at once from a perspective point like an x-ray machine. Thankfully, this registration error can easily be removed by:

1. Resizing the CT volume along the patient's vertical axis according to the volume's distance from the "x-ray source"
2. Modifying the raycasting algorithm to use orthographic projection along the CT volume's vertical axis and perspective projection for the other two axes

An example of a resulting DRR can be seen in Figure 2.

2.3 Statistical Analysis of Femur Shapes

This step marks the research's current stage in development. The objective is to discover the parameters that best describe the variations in 3D femur shapes- especially those that might suggest the presence of FAIs. This phase will be performed as follows:

1. **Region of Interest Selection.** The femoral heads found in each patient's segmented CT data are fitted with a 3D bounding box
2. **Normalization.** The contents of each bounding box are converted into a standardized format, dimension, position, orientation, etc.
3. **Vectorization.** The contents of the normalized bounding boxes are converted into 1D vectors of voxel intensities
4. **PCA.** Principle Component Analysis is used to analyze patterns in the set of 1D vectors
5. **Parameterization.** The average femur shape is found in the PCA space along with the most influential parameters

2.4 Creating a 3D Femur from Two Radiographs

Creating the 3D femur shape from the 2D radiographs is the final phase of the proposed procedure. It will be done as follows:

1. Starting from the average femur shape, the PCA space is searched until the contours (and contents) of the parameterized femur's DRRs match best with those from the segmented radiographs
2. Reverse any normalization of the parameterized femur to obtain the corresponding 3D femur shape

3 Conclusion

This paper describes a process by which, two or more pelvic radiographs can be used to recreate the 3D shape of a patient's femur. This work's aim is supply physicians with an additional tool to diagnose FAIs. Areas of future work include reconstructing 3D acetabulums along with whole femurs using the same radiographs as source material.

4 Acknowledgement

Funding for G. Telles O'Neill's research was provided from the Natural Sciences and Engineering Research Council (NSERC).

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