3D Femur Skeletonization using Maximum-Minimum Centre Approach

Saw Seow Hui\textsuperscript{1}, Ewe Hong Tat\textsuperscript{1}, Ji Wan Kim\textsuperscript{2}, and Byung Gook Lee\textsuperscript{3}

\textsuperscript{1}Universiti Tunku Abdul Rahman, Malaysia
\textsuperscript{2}Asan Medical Center, University of Ulsan College of Medicine, South Korea
\textsuperscript{3}Dongseo Univ., South Korea

Abstract

Femoral shaft fractures have been correlated with frequent morbidity and mortality. It is a major musculoskeletal disorder caused by tremendous force being applied to the femur. One of the most common surgical treatments for fixation is the intramedullary nailing, which utilizes a specially designed metal rod and screws to be implanted into medullary canal. However, severe bowing of the femur can result in mismatch between the intramedullary nail and the alignment of the femur. Such mismatch is a risk factor for anterior cortical perforation of the distal femur with subtrochanteric fractures, and leg length discrepancy with fractures of the femoral shaft. Therefore, the exact data of the femur geometry is mandatory to develope and apply intramedullary nail for bowed femur. This research is to develop an automatic approach with direct extraction of the skeleton from a 3D femur for each individual patient, in order to produce an accurate 3D preoperative simulation possible. While the 3D femur is generated from a set of computed tomography images. The efficient and robust 3D skeletonization based on maximum-minimum centre approach will be discussed in this paper. The proposed approach can potentially be assisted for the implant measurements. Several examples are included to demonstrate that the proposed approach works well for several 3D femurs.

1 Introduction

Three-dimensional (3D) skeletonization provides an alternative to capture the inner structure of an overall complex 3D mesh by forming its own skeletons. These computed skeletons consist of significant geometric and topological information that are used extensively to produce segmentation for various analyses and visualization in medical imaging, robotics and video surveillance applications.

Although the development of 2D skeletonization is relatively well established, but the skeleton computation in 3D is yet a challenging task for both researchers and practitioners. And, it is definitely worth to be explored in the study of orthopaedics especially the human femur.

The femur is the longest, heaviest and strongest bone in our human body. Different kinds of trauma with a lot of forces can damage this bone, such as in some motor vehicle accidents or motorcycle crash. This can also happen in a lower-force accident, such as fall from slippery floor, ladder landing on foot among the older people due to their weaker bones or osteoporosis. Femoral fractures usually require, open reduction internal fixation (ORIF) with intramedullary nail or plate to repair and heal the broken bones.

As for the ORIF, it consists of two procedures performed by an orthopaedic surgeon under anaesthesia: open reduction and internal fixation [1]. ORIF involves reduction of the fracture and apply an internal fixation device such as an intramedullary nail (usually made of titanium) into the medullary canal in order to stabilize the fracture until bone union. This procedure is also known as intramedullary nailing and involves the use of other special types of implants including metal plates, screws, stainless steel pins and wires.

Intramedullary nailing is one of the most common surgical treatment for femoral fracture fixation. Hence, the preoperative planning template is an essential prerequisite to estimate the correct nail diameter and length for the success of orthopaedic procedures [3].

However, mismatch problem of current available nail with bowed femurs and an accurate and automatic 3D preoperative simulation are therefore desirable.

2 Skeletonization using Max-Min Center

There are mainly three processes to compute as illustrated in Figure 1. It begins with the individual snapshots of the individual human femur into a set of cross-sectional images, which also known as Computed Tomography (CT) imaging. These images are used to produce three-dimensional (3D) samplings of anatomy elements for the human femur. With the use of reconstruction and parametrization from such datasets, the structured data (in the form of .obj format) can be obtained to form a 3D model.

![Figure 1: The three main processes.](image)

The final process is the skeletonization to obtain the compact representation of the femur. The earliest approach for the skeleton extraction is the medial axis transform (MAT) proposed by Blum [2]. MAT is mainly composed of two properties: the medial axis (MA) and the radius function. Medial axis (MA) for a given object $\Omega$ is defined as the loci of all maximal inscribed disks that meets two or more boundary points without crossing any of the boundaries.

$$MAT(\Omega) = \{(p, r) \in R^n \times R|B_r(p) \text{ is maximal ball in } \Omega\}$$

$$MA(\Omega) = \{p \in R^n|r \geq 0 \text{ s.t. } (p, r) \in MAT(\Omega)\}$$

In order to obtain a detailed information of the object, each point on the medial axis is associated with the radius function which form the medial circle. The volume enclosed by the surface of the object is exactly the union of these circles.

To obtain the skeleton of the 3D femur, we try to find maximum radius of circle that can fit into the irregular inner polygon of the slice 3D femur data. We use the following steps to obtain a reliable skeleton.
1. Sliding process: at first time we decided sliding window with appropriate height \( h \), and we collect vertexes in sliding window,

\[ V_s = \{ v : v_z \in (z, z + h) \} \]

where \( v = (v_x, v_y, v_z) \in \mathbb{R}^3 \), \( s = (z, z + h) \).

2. Adjacent face: obtain the faces adjacent to the points in \( V_s \),

\[ F_s = [ [V_s] ] = \{ f_i \}_{i=0}^{m}. \]

3. Weighted center point: calculate the weighted average of \( F_s \),

\[ \bar{F}_s = \frac{1}{A_s} \sum_{i=0}^{m} A(f_i) \bar{f}_i, \]

where \( A_s = \sum_{i=0}^{m} A(f_i) \), \( A(f_i) = \text{area of a triangle } f_i \), and \( \bar{f}_i = \text{center of a triangle } f_i \).

4. Slice plane: calculate the weighted average of the face normal sliding window base plane: face normal average:

5. Inner slice polygon \( \Omega_s \): projection face center to base plane

6. Max-Min Center: \( B_s(p, r) \) is maximal circle in \( \Omega_s \)

In this research, we have proposed maximum-minimum centre approach to obtain a reliable skeleton of the 3D femur. In the future, if a lot of relevant data is accumulated, we will develop a more efficient algorithm using artificial intelligence theory. The 3D femur skeletonization would give better understanding of the geometry and help to prepare and develop new intramedullary nailing system.

![Figure 2: Sliding window: 2 green circle, Adjacent face: brown triangle faces.](image)

![Figure 3: Weighted center point: green point, Inner slice polygon: blue points, Maximal circle \( B_s(p, r) \): green circle and line.](image)

![Figure 4: The 3D femur skeletonization result: green lines.](image)

**Acknowledgement**

This work was supported by Institute for Information and Communications Technology Promotion (IITP) grant funded by the Korea government (MSIT) (No.2018-0-00245, Development of prevention technology against AI dysfunction induced by deception attack)

**References**