Automatic method to determine anatomical coordinate systems for 3D bone models of isolated arthritic knee

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Abstract – We present and evaluate an automatic method to define anatomical coordinate systems (ACSs) for 3D bone models of isolated arthritic knee. The method has acceptable repeatability and can also be used for the bone shape alignment.

Keywords— 3D bone model, automation, shape alignment, medical imaging, shape analysis.

I. INTRODUCTION

A unique definition of anatomical coordinate systems (ACSSs) for 3D bone models of arthritic knee is required for comparison of anatomical measurements (e.g., location and orientation of landmarks) between different models. ACSSs can also be used to align the bone models into common coordinate frame for comparison of shapes or statistical shape analysis. Alignment methods which are based on surface registration are dependent on an additional template shape [1]. Daniel et al. presented a method where the ACSs were established from the articulating surfaces of the knee bones [2]. However, the articulating surfaces are usually damaged in case of arthritic knee. Hence, we present and evaluate a new method to define ACSs for 3D models of distal femur and proximal tibia.

II. METHODS

Twenty sets of CT images of the knee joint of arthritic patients (4 male, 16 female, aged 65±12 years) were acquired preoperatively after a written consent. From the CT images 3D surface models (≈ 50,000 points) were generated using medical modeling software (Mimics 10.1, Materialise). The primary axis of femoral ACS was determined from femoral diaphysis. Diaphysis was separated from the femur by measuring the variation in the axial cross-sectional area along the axis of the Cartesian coordinate system whose direction was closer to that of the longitudinal axis, by default. A typical cross-sectional area variation curve is shown in Fig. 1(a). The diaphysis was separated at the point corresponding to the inflection point of the curve Fig. 1(a).

A cylinder was fitted to the surface points of the diaphysis using Matlab-based Gauss-Newton algorithm. The axis of the fitted cylinder is the primary axis. To get the other two axes, all the surface points were projected on a plane perpendicular to the primary axis. Principal component analysis (PCA) was performed on the projected points and principal axes were calculated. The 1st and 2nd principal axes give the directions of the required medial-lateral (ML) and anterior-posterior (AP) axes respectively (Fig. 1(b)). The origin of the femoral ACS was positioned at the epiphysis’s centroid. Figure 2 is showing the whole process of determining the femoral ACS and aligning it with Cartesian coordinate system.

Tibial ACS was also determined using the similar method as applied to the femur. Tibial plateau was separated from its shaft using the similar method as used for separating the femoral epiphysis. Primary axis was determined by fitting cylinder to the tibial shaft and the other two axes were determined from the separated tibial plateau by using PCA. The origin of tibial ACS was positioned at the centroid of tibial plateau.

III. RESULTS

After determining the ACSs, all the bone models were aligned to a template bone by surface registration which was performed using point cloud processing software (CloudCompare 2.4, Telecom ParisTech). The method’s repeatability was evaluated by calculating the differences in location of the origin (absolute 3D distance) and angular orientation (3D angle between x-, y- and z- axes) of each ACS compared to the mean ACS, for both femur and tibia. The mean ACS was determined by averaging each ACS’s origins and axes.

The average absolute 3D location and orientation differences were mostly below 0.5 mm and 1.5 degree respectively (Table I). The results show that the repeatability of our method is better than that of the method presented by Daniel et al. [2]. This also shows that the bone model alignment which can be achieved by matching the ACSs determined by our method is close to the alignment which can be achieved by the surface registration based methods.
Fig. 1  (a) Separation of diaphysis using cross-sectional area variation curve (b) Determined axes of femoral ACS

![Diagram showing separation of diaphysis and determination of axes](image)

Table 1 Results showing repeatability of the proposed method

<table>
<thead>
<tr>
<th>Study</th>
<th>Location difference (mm)</th>
<th>Orientation difference (degree)</th>
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<tbody>
<tr>
<td></td>
<td>F</td>
<td>T</td>
</tr>
<tr>
<td>Our Method</td>
<td>0.3, 0.1</td>
<td>0.4, 0.1</td>
</tr>
<tr>
<td>Danjial et al. [2]</td>
<td>1.7, 0.4</td>
<td>1.1, 0.4</td>
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Results are in the form of Mean, 95% Confidence; F-femur, T-tibia
IV. Conclusions

We conclude that our method has acceptable repeatability and can be used as an alternative to surface registration, to align isolated arthritic knee bones without a need of template.

Conflict of Interest

The authors declare that they have no conflict of interest.

References