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グローバルCOE「医・工・情報学の融合による予測医学基盤創成」
－*in silico* medicine を指向したオープンプラットフォームの構築－

グローバルCOEプログラム

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■報告■

This is the second time I came to Osaka University. During this one week trip, I learned a lot from Prof Takada and Dr. Yagi. Dr. Yagi helped me to improve my segmentation method and Prof Takada helped to figure out more possible application of the segmentation method I am using.

The 3D segmentation of tooth is carried out with the 3D Region Competition Snakes in ITK-SNAP. It is a raw segmentation. Thus a manual refinement of the tooth model is still needed. The whole segmentation process will cost us more than 15 minutes. This may not be a problem for pilot study, however, when it comes to a large datasets like hundreds of teeth, an automatic segmentation method is still in need. The two main problems of segmentation of tooth in CT images are segmentation of touching crown and segmentation of root of the tooth from its periodontal alveolar bone. Gao et al. firstly used coupled level set method to segment the touching crown of the adjacent teeth. They then integrate the 3D level set method with shape and intensity prior to segment the tooth root with single level set and the crown with coupled level set. The future work on automatic segmentation of tooth in CBCT will be firstly testing their algorithm on our hundreds tooth datasets to see whether it is a general applicable method. If it is not general enough, we still need to develop such an automatic method for segmentation the tooth from CBCT.

As to the problem MRI bone segmentation, a lot of researchers proposed to use Statistical Shape Model (SSM) or appearance model. Kainmueller et al. built the SSM of the mandible from 106 CBCT datasets. The mandible was segmented manually by a dentist. The segmented surface mesh was separated into six patches. The main steps of the method are global initialization, statistical shape adaptation and constrained multi-object free-form deformation.

Figure: The six patches of the SSM of the mandible

Similar method is proposed by Babalola. Although their method works on mandible segmentation from CBCT, the methods may fail for segmentation of mandible in MRI due to the poor imaging result for hard tissues.
Some of the difficulties for implementation of the SSM or AAM algorithm for mandible segmentation in MRI are summarized below:

(1) As it is reported by Kainmueller et al., their SSM model of mandible is generated from 106 CBCT datasets. Usually, patients do not have to undergo the CBCT imaging for normal treatment, instead, dentist only take a small FOV imaging for certain small area. Thus to get hundreds of mandible CBCT datasets is very difficult. Even if the CBCT datasets are already obtained. The generation of the 3D SSM of mandible is still a very time consuming process. A lot of manual segmentation is inevitable. The segmentation of a mandible accurately from CBCT has workload of more than two hours.

(2) The segmentation of mandible in CBCT datasets does not give too much concern to the “leakage” problem which is very common in MRI mandible datasets.

(3) In CBCT datasets, the mandible is a large connected component in 3D. However, in MRI, the mandible is usually consisted of plenty of small fragments.

(4) As reported in the first study of this report, the coronoid process and the TMJ of the mandible are the most difficult parts to be segmented even manually.

Segmentation of mandibular shape in MRI is still a challenging task, however, the integration of SSM with advanced segmentation method, say active contour and graph cut, may offer us an acceptable result.

Another important idea I got through this trip is to study the complexity of moving impacted tooth. Before we study the real world model of the issue. We have to first the mechanics of tooth movement.

"Orthodontic forces can be treated mathematically as vectors. When more than one force is applied to a tooth, the forces can be combined to determine a single overall resultant. Forces produce either translation (bodily movement), rotation, or a combination of translation and rotation, depending upon the relationship of the line of action of the force to the center of resistance of the tooth. The tendency to rotate is due to the moment of the force, which is equal to force magnitude multiplied by the perpendicular distance of the line of action to the center of resistance. The only force system that can produce pure rotation (a moment with no net force) is a couple, which is two equal and opposite, noncolinear but parallel forces." [1]

The next step is to determine the translation vector and the rotation vector from the original position (pre-treatment) of the tooth to its final position (post-treatment).

Assume the translation force $\overrightarrow{F_T}$ is a constant force. The translation vector is $\vec{S}$. The translation energy $\overrightarrow{E_T}$ can be calculated as $E_T = \overrightarrow{F_T} \cdot \vec{S}$. Assume the rotation force $\overrightarrow{F_R}$ is a constant force. The radius from the rotation center and the point where the force applied is $\vec{r}$. The initial and final angular positions of the body is θ. The rotation energy $\overrightarrow{E_T}$ can be calculated as $E_R = \overrightarrow{F_R} \times r \cdot \theta$. The total energy cost can be calculated as

$$E = E_T + E_R = \overrightarrow{F_T} \cdot \vec{S} + \overrightarrow{F_R} \times r \cdot \theta$$

Given the original position P_o to final position P_F. We can only find the transformation matrix T, $P_F = TP_o$. Thus $T = P_F P_o^{-1}$. The path from original position to final position is not unique (different couple of $\vec{\mathbf{S}}$ and $\boldsymbol{\theta}$). It will cost different amount of energy given different paths. The first problem is whether there exists a solvable minimum energy E_{min}, given the magnitude of $\overrightarrow{F_T}$ and $\overrightarrow{F_R}$ are constants and $T_t T_R = T$ (The constraint of the optimization problem). If the answer is yes, we may define the complexity of the treatment depending on this minimum energy E_{min}. The treatment with the greatest should be considered as most complex one.

Thanks to Prof. Takada, Dr. Yagi's guide on my research, I could get more and more new idea to continue doing after I returned to National University of Singapore.

Thanks Osaka University very much to support my trip to Japan.

[1] Smith RJ, Burstone CJ. Mechanics of tooth movement. Am J Orthod. 1984;85:294□307.