Tooth Frame Axes and Centroid for Dental Occlusal System

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ABSTRACT

In dentistry, determining position and orientation parameters for each tooth mostly based on orthodontic qualitative perception. There is no quantitative method to obtain those parameters in three dimensional (3D) images, especially in some complicated cases. This study proposed a quantitative approach for locating centroid of tooth position and also its frame axes orientation. Based on Cone Beam Computed Tomography (CBCT) x-ray images, a 3D model of teeth was obtained to visualise dental features. A few dental features were used to calibrate the location of centroid and identify tooth reference axes, or frames. Two definitions of centroid and frame axes were proposed for single root and for multiple roots of teeth. Based on these two definitions, the positions and orientations of each tooth were determined and evaluated. Teeth positions and orientations were obtained with respect to a reference axis, which is the CBCT coordinate system. Having a quantitative method to obtain position and orientation of tooth, especially in 3D, will help dental rehabilitation in many ways.

Keywords: Centroid, orientation, position, dental occlusion, reference axes

INTRODUCTION

To improve the result of dental rehabilitation, there are efforts to introduced three-dimensional dental geometry model. Dental cast might be one of the methods to get a 3D view of a dental occlusion, but the digital models gave more advantages such as the possibility of special registration. Digital models were able to combine the collected data from different time points in one coordinate system (Grauer & Proffit, 2011). In timely manner, most of the digital models in orthodontic observation were in 2-dimensional (2D) grayscale. This causes problem when the images overlap each other and are difficult to distinguish in complicated...
cases (Esa, Ayub, & Ali, 2012; Manzi et al., 2012). Later, cone-beam computed tomography (CBCT) was introduced for dental practitioners to be able to get multi-planes of dental imaging (Scarfe, Farman, & Sukovic, 2006). By using CBCT, they do not only able to have thin layer images in axial plane, but also able to view images in curved, oblique, sagittal, and coronal images plane (Aziz, Ayub, & Jaafar, 2012). Not just 2-dimensional (2D) images, CBCT is also able to provide a 3-dimensional information by reforming its data in a volume (McCoy, 2013).

To be specific, this technology is also called Cone Beam Volume Imaging/Tomography (CBVI/CBVT). This term is used to differentiate it from the connection medical computed tomography (CT). The image capture is generally a single 190˚ up to 360˚ scan sweep around the patient’s head. Using “cone-beam” shaped x-ray aimed at a solid-state panel detector, the desired image volume can be covered in a single scan. Compared to medical CT, this single scan of CBVI approach is able to decrease x-ray dose from six to fifteen times during the 3D imaging examination (McCoy, 2007). However CBVI/CBVT technology does not provide analysis tools such as teeth position, teeth orientation and accurate geometry characteristics or parameters.

To determine the position and orientation of teeth, the location of centroid must first be defined. Since the definition of centroid for teeth is still not established, there are few definitions available depending on its relevance in the study. One definition is just a simple mid-point of the tooth, from the top to the bottom. The other definition is that the centroid of tooth is approximately 1/3 from the root, measured from the root to the end of the tooth crown (Burstone & Nanda, 1993). Alternatively, other researchers proposed using landmarks of the tooth to find the centroid. During molar translation, four landmarks were digitised on each molar at each time point, and then the centroid position was constructed and computed (Grauer & Proffit, 2011; Peixoto, Pinto, Garib, & Gonçalves, 2014).

The aim of this paper is to define a centroid and frame axes for each tooth in order to determine teeth position and orientation in 3D from the CBCT images. In this research, the images from CBCT scans of a patient were taken from dentistry databank in order to eliminate ethical issue. Hence, the images taken were not a real-time image data acquisition. The images can be manipulated in several views such as front, top, and side views. A user can view the x-ray images in 2D or 3D and no analysis function is available.

**METHOD**

This study used a set of teeth from one patient to be analysed and focused on defining the centroid of the teeth and reference axis. Only seven teeth at the lower jaw on the left side of a patient were taken from x-ray image to determine the position and orientation of each tooth corresponding to the reference axis. In this study, one of the teeth with clearest view on the x-ray image was analysed using image processing algorithm to obtain more precise parameters. A 3D modelling using Computer Aided Design (CAD) software was made beforehand based on the parameters from the x-ray images to get better 3D view (Ayub, Mohamed, & Esa, 2014). Figure 1 shows the flow of the research method employed in this study. There are six stages involved in this study. The research started with thorough literature review on the subject matter, followed by modelling of dental geometry structure, defining centroid and reference
axis, image processing, data collection and analysis, and finally, the report writing. However, this paper focused only on defining centroid location (tooth position), tooth frame axes (tooth orientation), and reference axes.

Figure 1. Overall research method

In this study, centroid is defined as \( \frac{1}{3} \) of the length (L) measured from root to crown end, as shown in Figure 2, while for a tooth with more than one root, its centroid is defined as the bifurcation point. Bifurcation is the point where tooth roots start to divide, as shown in Figure 3. The x-ray images from cone beam computed tomography (CBCT) showing images slice by slice from all views but the image in two-dimensional (2D) were used in this study (Figure 4). Figure 4 shows the orthographic view of the dental occlusal, which consists of plan view (XZ reference axis), side view (YZ reference axis), and front view (YX reference axis). After several calibration processes, starting with the side view, the centroid location at the side view was determined. Then, the tooth image in side view was rotated so that the tooth is in the upright orientation parallel with vertical line of Y-axis. This approach was used in order to get
a true length of the tooth in front view. From that, the centroid from the front view is located. For the plan view, it is automatically located when both side and front view are determined.

The determination of tooth orientation is done after locating the centroid position. Using the cone beam coordinate system as reference frame, the orientations are measured from its respective axes using image processing algorithm developed in this study. For a single root tooth, a straight line that will pass through 3 points of dental features, which are the root, centroid, and peak point of a tooth are constructed and considered as the Y-axis of the tooth frame. For the tooth with multiple roots, a straight line that passes through 3 points of dental features (the root, centroid, and lowest point of the top tooth surface) are used. The Cartesian coordinate of X-axis is perpendicular to Y-axis and pass through the centroid point. Similarly, Z-axis is constructed accordingly using the right hand rule Cartesian coordinate system shown in Figure 5. The orientation of a tooth is configured as follows; rotation in X-axis is yaw ($\Psi$), rotation in Y-axis is pitch ($\theta$), and rotation in Z-axis is roll ($\phi$).

A reference axis is needed to fix the position and orientation of a tooth in the overall Cartesian coordinate ($x$, $y$, $z$) of dental occlusal system. The position of centroid is measured from the reference axes; thus, the reference axes must be fixed and remained unchanged at any circumstances. The orthographic view of CBCT was chosen since it provides all three-dimensional view and its default cone beam coordinate system was used as the reference axis. Figure 6 shows the position of the centroid and orientation of the tooth axes with respect to the reference axes of CBCT for the three adjacent teeth, LR1, LR2, and LR3.

![Figure 2. Centroid for single root](image1)
![Figure 3. Centroid for multiple roots](image2)
Results and Discussion

Table 1 shows the results of the centroid position in dental configuration system. The heading of the table are as follows: tooth names, centroid position, the length of teeth, and distance of the centroid from the root. The centroid positions are the reference axes of the CBCT. In this study, the targeted teeth are the seven teeth of the lower right jaw, excluding the wisdom tooth. Those teeth are represented by LR1 until LR7 in the first column, with the names of the teeth given in the second column. LR is the acronym for “lower right”, which refers to the teeth at the lower right jaw. Numbers 1 until 7 represent the tooth from incisor until molar accordingly. The centroid position of tooth is divided into three column, Xc, Yc, and Zc. Two columns on the right are the additional data gathered during the process of locating centroid.

The overall position of the dental system for the lower right jaw is shown in Figure 7. The centroid position along x-axis is Xc, which is measured from y-axis, was decreasing from LR1 to LR7. This trend indicates the position of the teeth was getting closer to the y-axis as it...
measures from LR1 to LR7 accordingly. Zc is the centroid position along the z-axis, which was measured from the x-axis. However, Yc is the position along the y-axis and it was observed that the positions are almost the same from LR1 until LR5 with a slight decrease from LR1 to LR2. The positions start to increase for LR6 and LR7 because the locations of LR6 and LR7 centroids are quite significantly different. It is worth to highlight here that LR1 until LR5 are teeth with single root, thus their centroid are at the root. However, LR6 and LR7 are the teeth with four roots, so their centroid are according to the bifurcation point, which is above the roots. That is why LR6 and LR7 positions on the y-axis are higher than the others. If LR6 and LR7 were replaced with one root tooth, the position will still slightly increase because of the bone shape that is holding the teeth. If we look into the perspective of the frame view, Yc is viewed from side view (YZ frame) and it also can be viewed from the front view (YX frame). However, Xc and Zc can be viewed only from the plan view (ZX frame). Figure 4 shows the plan view of the arc of the teeth arrangement which results in such trend for Xc and Zc.

### Table 1

**Position of the centroid of teeth**

<table>
<thead>
<tr>
<th>Tooth</th>
<th>Tooth's name</th>
<th>Xc</th>
<th>Yc</th>
<th>Zc</th>
<th>Distance from root to top of teeth (mm)</th>
<th>Distance centroid from root (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR1</td>
<td>Central incisor</td>
<td>80.0</td>
<td>35.2</td>
<td>132.8</td>
<td>19.81</td>
<td>3.58</td>
</tr>
<tr>
<td>LR2</td>
<td>Lateral incisor</td>
<td>76.8</td>
<td>33.6</td>
<td>130.0</td>
<td>23.49</td>
<td>4.15</td>
</tr>
<tr>
<td>LR3</td>
<td>Canine (cuspid)</td>
<td>71.0</td>
<td>33.6</td>
<td>127.0</td>
<td>21.53</td>
<td>4.25</td>
</tr>
<tr>
<td>LR4</td>
<td>First premolar (bicuspid)</td>
<td>66.8</td>
<td>33.6</td>
<td>123.6</td>
<td>18.26</td>
<td>4.30</td>
</tr>
<tr>
<td>LR5</td>
<td>Second premolar</td>
<td>62.8</td>
<td>35.6</td>
<td>117.2</td>
<td>17.55</td>
<td>4.41</td>
</tr>
<tr>
<td>LR6</td>
<td>First molar</td>
<td>58.4</td>
<td>42.4</td>
<td>110.4</td>
<td>16.49</td>
<td>8.10</td>
</tr>
<tr>
<td>LR7</td>
<td>Second molar</td>
<td>55.6</td>
<td>46.4</td>
<td>98.8</td>
<td>14.54</td>
<td>5.69</td>
</tr>
</tbody>
</table>

![Figure 7. Centroid position of teeth](image-url)
The orientation of tooth was calculated using simple trigonometric functions. The right hand rule Cartesian coordinate system was used to indicate the direction of the orientation which gave the value positive or negative. The results are shown in Table 2. The symbols $\alpha$, $\phi$, and $\theta$ represent the angles of tooth in x-axis, y-axis, and z-axis, respectively. The largest angle for $\alpha$ is LR1, with an angle of 42.10°, while for $\phi$ is LR7 with an angle of -72.92°, and for $\theta$ is also LR7 with an angle of -15.94°.

The profiles of teeth orientations are shown in Figure 8. For the angles $\alpha$ and $\phi$, the profile decreases slightly but not obviously, especially for $\alpha$. In general, the profile of the angle $\phi$ is in the downward trend. For angle $\theta$, the graph shows a fluctuating profile. The images of teeth were taken from a patient with dental occlusal problem, so some of the orientations are not according to the normal value.

The downward trend of profile for angle $\phi$ is significant due to the arc shape of the teeth arrangement. The difference of angle from LR1 until LR3 is small, but it starts to get bigger from LR4 until LR7. Based on this result, LR4 can be considered as the turning point of the arc shape. For the angle $\theta$, it is viewed from the front view, and the fluctuating profile indicates that the teeth are not in a good arrangement. Some are rotated to the left, while others are rotated to the right. From the side view, it shows the angle $\alpha$ with a decreasing profile from LR1, which is incisor tooth, up to LR6, which is the first molar tooth. However, at the second molar tooth (LR7), the angle $\alpha$ is slightly higher. For normal tooth occlusal, the angle $\alpha$, $\phi$, and $\theta$ of orientations are not necessarily at 0°. Each tooth has its own respective angles of orientation to meet the functionality and aesthetic appearance of the dental occlusal. The overall modelling of the teeth positions and orientations in CAD are shown in Figure 9.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Orientation of the teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooth</td>
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</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>LR1</td>
<td>Central incisor</td>
</tr>
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<td>LR4</td>
<td>First premolar (bicuspid)</td>
</tr>
<tr>
<td>LR5</td>
<td>Second premolar</td>
</tr>
<tr>
<td>LR6</td>
<td>First molar</td>
</tr>
<tr>
<td>LR7</td>
<td>Second molar</td>
</tr>
</tbody>
</table>
CONCLUSION

A more effective interaction between dentist and imaging machine will provide a better dental treatment to patients. One way to get this effective interaction is by developing a more comprehensive model of dental information from the imaging machine and sharing with dentists to harness human flexible and reasoning capability, coupled with the machine accuracy, repeatability and fast operation capability. A quantitative method to determine teeth positions and orientations is very important for dental rehabilitation. Currently, the positions and orientations are mostly based on orthodontic qualitative perception. This paper has successfully proposed a standard method to obtain those values in three dimensional (3D) CBCT images. A suitable definition for the centroid of tooth, orientation of tooth and also its reference axes to determine teeth position and orientation have been highlighted. The analysis of the results from this study shows that the positions and orientations of teeth are in accordance with the actual dental occlusal. The results have been verified with the experienced orthodontic personnel. Having the quantitative method to obtain the position and orientation of tooth especially in 3D will help dentists in many ways.

Figure 8. Orientation of teeth

Figure 9. A 3D modelling of teeth position and orientation
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dental occlusal. The results have been verified with the experienced orthodontic personnel. Having the quantitative method to obtain the position and orientation of tooth especially in 3D will help dentists in many ways.

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