Abstract

This paper is a part of the development on 3D orthodontic diagnosis and treatment planning system using Borland C++ Builder and OpenGL. The purpose of this article is to describe a quick and easy method on mesh cutting using planes which started from a complete 3-dimensional view of the dental cast in STL format, and follows with the mesh cutting technique on the digital model. Users can cut and separate each tooth from the dental cast by simply drawing a line on the cast in 3D. Then program will generate the vertical plane to obtain the cutting results. Next an interactive treatment planning technique is developed that permits a user to move teeth from the dental cast to a proposed set-up. This can be done either semi-automatically or manually to setup each tooth to lie along the arch form curve for treatment plan. After the digital model has been setup and planning, then the algorithm will provide the ability to display a virtual bracket placed on each tooth. Then both teeth and brackets can transform from the original position to the virtual final outcome as the orthodontics labial treatment simulation in a step by step.

1. Introduction

The dental casts made from the plaster of Paris have been applied in orthodontics for a long time. Traditionally, the clinicians obtain the dental cast and analyze with it manually. Until now, imaging technology for orthodontics diagnostic and treatment planning has been used worldwide. There are many research topics on the orthodontics simulation, orthodontics treatment planning and so on. Some commercial products are also used in the present such as OrthoCAD [1], a product of Cadent Inc., developed for computer-aided treatment, 3Dxer [2], the product by Dimennex Digital Lab has been used for orthodontics analysis, e-model [3], from Geodigm Corp is another 3D digital model service for orthodontics diagnostic. However, all diagnostics from the commercial are limited to provide only services and the commercial software sets are expensive. However, there are some researches for aided orthodontics in analysis of the dental cast. For example, the work by Motohashi showed the computed surgical simulation of the patients [4] which still in the research area. The work by Kondo and et.al was very well for automatic tooth extraction from the cast but it fails for severe overlap of two adjoining teeth which can not be used in real application. Our previous work [5] had presented the manipulation of the dental cast using 3D thin plate spline in order to arrange the teeth to lie along the curve. But with the thin plate spline technique, the shape of the tooth had been changed and was not be able to accept in clinical area. And another work had presented the 3D orthodontic treatment simulation with tooth segmentation by locating landmarks and applies region mesh growing [6]. However it is quite slow to locate the landmarks on each tooth manually. Therefore, in this article presents the developing of software algorithms for the computer simulation of the diagnostic cast using quick and easy mesh cutting method. Then the virtual brackets were designed and placed on the surface of each tooth. Finally, the development of the mesh cutting tooth and re-arrange to lie along the curve with the virtual brackets attached would help the clinician in diagnostic, planning, predicting, displaying the treatment and showing this simulation to the patient.

2. Methods

2.1 Three Dimensional Interface

3D Graphics User Interface for displaying the 3D STL data which is a triangular representation of a 3D surface geometry is designed using Borland C++ Builder™ with TMS modules and OpenGL as can be seen in figure 1. We design the GUI to let the user be able to locate the landmarks on the 3D object surface. Normally when the user clicks on the screen, it is
recognized in screen coordinates. Then the screen
coordinates need to be converted to 3D model
coordinates using gluUnproject function from openGL
library. To use this method to find the x, y and z
coordinate of where the mouse has been clicked,
several variables has to passed to the function such as
view port origin and extent, modelview Matrix,
projection matrix and the windows screen coordinate
which can be obtained using some opengl functions
[7]. Apart from the graphics user interface, the users
need to locate the occlusal landmarks on the top of
each tooth or at some selected teeth and apply cubic
spline technique [8] to fit the landmark as the trace line
positions in 3D. Once locating occlusal landmarks, the
cubic spline algorithm will be executed to generate
trace line and the landmarks.

![Figure 1: The Graphics User Interface of 3D orthodontic diagnosis and treatment plan system, which displays the dental cast in 3D with cubic spline fitting on occlusal landmarks (Red dot landmarks). The users allow interacting with the objects such as rotate, zoom and pan.](image)

The cubic spline consists of sections of polynomial
curves connected at these landmarks. The polynomials
of a given spline all have the same degree in X, Y and
Z and fit the control points as 3D line. The spline is
obtained by calculating the second derivatives of the
interpolating function at the tabulated points based on
the formulation given in “Numerical Recipes in C”. [8]
But in our work, some modification has been applied
by changing from one dimension to three dimensions
cubic spline. In this paper, a data point is equivalent to
the number of teeth on the dental cast. The result of
fitting the 3D line with cubic-spline interpolation can
be seen as in figure 1.

2.2 Mesh Cutting Technique

Mesh cutting technique is applied by first
creating the horizontal plane that parallel to the
average of occlusal landmarks planar as can be seen in
figure 2. The horizontal plane can be defined by a
normal vector \( <nx,ny,nz> \) which perpendicular to the
occlusal planar as well. This horizontal plane can slide
up and down along vertical axis.

In the plane equation the value \( k \) specifies
where exactly on the axis the plane sits. The Eq. 1 for
the plane uses the dot product:

\[
<x,y,z> \cdot <nx,ny,nz> = k
\]  

All points \( <x,y,z> \) that actually lie on the plane itself
will satisfy this equation. This gives us a convenient
method for determining each vertex of the cast weather
it lies is in upper side or lower side of the horizontal
plane by calculated the dot product between the normal
vector of plane and the vector for any given point
\( <x,y,z> \) as in Eq. 2:

\[
<x,y,z> \cdot <nx,ny,nz> = 0 \quad \text{Point is in plane}
\]
\[
<x,y,z> \cdot <nx,ny,nz> > 0 \quad \text{Point is on one side}
\]
\[
<x,y,z> \cdot <nx,ny,nz> < 0 \quad \text{Point is on another side}
\]

The result of Teeth that lies on the top of horizontal
plane can be seen in figure 2.

![Figure 2: Teeth that separate from the cast by horizontal plane cutting. The horizontal plane that uses to separate between Teeth and cast has shown under the dental crowns.](image)

Next step, the user needs to locate lines on the plane
manually, and then the program will calculate and
generate the vertical planes automatically to separate
each tooth from teeth and label into different colors as
can be seen in figure3. The technique to segment each
tooth is similar to the plane cutting as describe in
horizontal plane cutting above. Except for vertical
planes cutting, each vertex on teeth is determined if it
lies in between two planes not only one plane.
2.3 Model Setup and Planning

Final step is the alignment of the individual tooth to lie along the dental arch which the dental arch is calculated from an appropriated size and shape of the occlusal landmarks (landmarks in figure 1). The technique for tooth alignment is start with the user locates the landmarks to indicate each tooth width. Therefore one tooth will have 2 landmarks point A and point B for representing the tooth width as shown in figure 4. The right hand side of figure 4 shows the teeth lines indicates the tooth width, which lie into different directions in corresponding to the tooth positions.

Then program will simulate the pre-operative orthodontics treatment for the whole teeth. This can be done by developing an automatically connection of each couple landmarks A and B and lying along the arch form curve. To adjust the positions of A and B of each tooth, means each individual tooth must be rotate and translate automatically to form all teeth into an arch form curve as can be seen in figure 5.

For adjusting the individual tooth, the procedure will need the algorithms for tooth rotation about an arbitrary axis [10] and translation. This can be done by calculating an arbitrary axis which is the cross product between the original position line (vector1) and the aligned line (vector2) as can be seen in figure 6.

Therefore, the angle (β) between two normal vectors, the direction of vector1 and the direction of vector 2, of each line width must now be calculated. It is also necessary to calculate the cross product between the vector1 and the vector2 to get the rotation axis. Then a rotation of angle (β) about this axis can be performed. The rotation can be done with a matrix as specified in Eq. 3. [9]

Then all teeth are automatically rotate into the direction as required. Next each individual tooth needs to translate to the aligned position followings to the width lines on the right hand side of figure 5.

Matrix for rotation about an arbitrary axis (3)

\[
\begin{align*}
\begin{bmatrix}
\cos \beta & \sin \beta & 0 \\
-\sin \beta & \cos \beta & 0 \\
0 & 0 & 1
\end{bmatrix}
\end{align*}
\]

Where c = cos (β), s = sin (β), t = 1-cos (β), and (X, Y, Z) is the unit vector representing an arbitrary axis (the cross product between vector1 and the vector2).

2.4 Virtual Brackets and Orthodontics Labial Treatment Simulation

For the orthodontics labial treatment simulation, the virtual brackets were designed and placed on to the surface of aligned teeth as can be seen in figure 7. Once the user placed the bracket on to the surface, all brackets were faced into the same direction. Therefore, the algorithm for rotate the bracket to lie along the surface has been developed with the same technique as described previous: rotate about an arbitrary axis. The result of the virtual bracket placed on each tooth has shown in figure 7.
3. Simulation Results

The experiment results show the teeth segmentation with the mesh cutting technique and computational simulation of pre-operative orthodontics treatment with the teeth and brackets move in a step by step from the final outcome to the original position as can be seen in figure 8. The simulation results also have been compared with the actual result and can be acceptable by the clinicians.

Figure 8: Simulation of the teeth and brackets movement from the final to original position.

4. Discussions & Conclusions

The segmentation on individual tooth has been performed using the tools provided in this paper: started from horizontal plane cutting to separate teeth from cast, then applied vertical planes to segment each tooth from teeth object. Finally, perform semi-automatic translated, rotated each tooth to lie a long the curve by locating the landmarks A and B and simulate of the pre-operative orthodontics treatment. The experiment results have shown that the techniques discussed here and used in the program based on the research is very well simulation tool for orthodontic applications. And this result could assists the clinicians for the treatment planning and also the patients can get an overall idea of what will affect to their teeth after the orthodontics treatment. However, the researchers have to study more on automatic segmentation. Next step after automatic segmentation is apply, the proper 3D mesh filling to fill the missing parts of individual teeth should be considered. These algorithms would allow users to perform teeth alignment with the perfect teeth. Nevertheless, the researchers have to study more on the anatomy and teeth movements from the clinicians as well, especially the angle and torque when the brackets force to the teeth to ensure that the simulation results would become closer to the actual results performed by the physicians.

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6. References