Design and Implementation of Software Simulation System for Dental Orthodontic Robot

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Abstract. With the development of society and the improvement of living standards, people's pursuit of their own beautiful appearance is getting higher and higher, especially the passion for beautiful features. Therefore, the demand for dental orthodontic surgery is growing in daily life. However, due to the limitations of oral physiological structure, the orthodontic brackets designed in traditional orthodontic surgery are often not the optimal dental arch shape for patients. Therefore, a dental orthodontic software system that can interactively simulate a patient's oral model is particularly important. In this paper, a software system of dental orthodontic robot which can simulate dental orthodontics was developed by using Blender secondary development technology combined with orthodontics and tooth extraction algorithm.

Keywords: dental orthodontics, dental robot, Blender, secondary development

1. Introduction
The main research task of orthodontics is to investigate the etiology of malocclusion and then to diagnose and prevent it. The orthodontic process is a process in which the dentist and the orthodontists cooperate to arrange the irregular teeth through the brackets [1]. The correction of dentition malformation mainly relies on the use of an internal or external orthodontic device to exert appropriate "biological force" on the teeth, alveolar bone and jaw bone to generate physiological movement, so as to correct the malformation [2]. The software system of dental orthodontic robot is a combination of orthodontic technology and computer-aided technology, which transforms orthodontic surgery into a simulation operation that can be interactively simulated in a computer.

The software system of the dental orthodontic robot studied in this paper is realized on Blender platform [3], which is further developed by using Python programming language. The simulated operation of orthodontics is performed in the software system studied in this paper, and then the data is transmitted to the robot system. The robot system uses ABB robot, model IRB 140TW. The communication between the software system and the robot system uses the Socket message communication method. The robot system adopts ABB robot, model IRB 140TW.Socket message is adopted to communicate between the software system and the robot system[4][5].

2. The overall structure of the dental orthodontic robot software system
First, we need to import the CT scan models of the patient's oral cavity into the software system, and then rearrange the patient's malformed dentition, which requires the use of the tooth arrangement algorithm. After that, the bracket model is imported from the standard bracket database. Finally, an appliance (braces) suitable for the patient's dental arch is designed according to the arranged dentition.
Therefore, the system structure diagram of the software system is shown in Figure 1. Figure 2 is a software system sidebar function button diagram.

![Software system structure diagram](image1)

![Software system sidebar function button diagram](image2)

3. Orthodontic tooth arrangement algorithm

3.1. Acquisition of dental arch curve

Dental arch curve refers to the arched parabola formed by the continuous arrangement of teeth in the upper and lower jaw bone on the alveolar bone [6]. It is a key step to obtain ideal dental arch curve and restore abnormal dental arch. There are many mathematical models of dental arch curve. By comparison, the β-function model is the closest mathematical model to the real tooth arch curve of human body, and the calculation is simple and stable.

The general formula of the β-function model is:

$$ Y = 3.0314 \times D \times \left[ \frac{X}{W} + \frac{1}{2} \right]^{0.8} \left[ \frac{1}{2} - \frac{X}{W} \right]^{0.8} $$

(1)

The general form can be simplified to:

$$ Y = D \times \left[ 1 - \left( \frac{2X}{W} \right)^2 \right]^{0.8} $$

(2)

Among them, W is the width of the third molar arch, that is, the distance between the distal and middle cheek points of the third molar on both sides of the mouth. D is the depth of the third molar arch, that is, the distance between the incisor and the third molar line on both sides of the mouth. The position-length relationship is shown in Figure 3.

It can be seen from the above that when the values of \( W \) and \( D \) are determined, the point \(((X_2 - X_1)/2, (Y_2 - Y_1)/2)\) is substituted into the above equation, and the value of \( e \) can be obtained. Figure 4 shows the effect of extracting the arch curve using the β-function model algorithm in the software system.
3.2. Calculation of tooth position

3.2.1. Calculation of tooth position coordinates. According to the physiological structure of the mouth, the coordinate system is established as shown in figure 5 below. Among them, the Z₀ axis is a straight line perpendicular to the maxillofacial surface, and the upward direction is positive. The intersection point of Z₀ and the maxillofacial is O₀, and the X₀-axis passes through the incisor and is parallel to the line of the third molars on both sides. The right of the observer is positive. The Y₀-axis is perpendicular to the X₀-axis, and the direction is shown in the figure. L is the dental arch curve.

After the reference coordinate system is established, we see the teeth as a rectangular parallelepiped arranged closely in sequence on the arch curve, as shown in Figure 6.

Since the number of standard teeth for humans is 16, the number of teeth in the half arch curve in the figure is 8. The \((X_i, Y_i)\) point in the figure is the far midpoint of the tooth. \((X_{i-1}, Y_{i-1})\) is the near midpoint of the tooth. And the \((X_0, Y_0)\) point is the origin of the coordinate system. Let the width of the cuboid representing the tooth be \(l_i\), then the following mathematical relation is satisfied in this coordinate system:

\[
(Y_i - Y_{i-1})^2 + (X_i - X_{i-1})^2 - l_i^2 = 0
\]  

(3)

Since both points of the cuboid are on the dental arch curve, the following mathematical relation can be obtained:

\[
Y_{i-1} = 3.0314 \times D \times \left[ \frac{X_{i-1}}{W} + \frac{1}{2} \right]^{0.8} \left[ \frac{1}{2} - \frac{X_{i-1}}{W} \right]^{0.8}
\]  

(4)

\[
Y_i = 3.0314 \times D \times \left[ \frac{X_i}{W} + \frac{1}{2} \right]^{0.8} \left[ \frac{1}{2} - \frac{X_i}{W} \right]^{0.8}
\]  

(5)
Since \((X_0, Y_0)\) is the origin of the coordinate system, \(X_0=0, Y_0=0\).

By using the above conditions and formula and the iterative calculation method, the point \((X_i, Y_i)\) \((i=0,1,2,3,\ldots,8)\) which is the position coordinate of the tooth on the curve of the dental arch.

### 3.2.2. Determination of tooth Angle

In order to show the angular attitude of a single tooth on the arch curve, we need to establish the single tooth coordinate system OXYZ as shown in Figure 7. In the figure, the Z axis is located on the plane of the arch curve and is tangent to the arch curve. The X axis is on the curve of the arch curve and perpendicular to the arch curve. The Y axis is perpendicular to the plane of the arch curve, so the angle relationship between the direction of a single tooth and the curve of the dental arch is shown in Figure 7.

![Figure 7. Single tooth angle coordinate system](image)

### 3.2.3. Application of AABB(axis-aligned bounding box)

After determining the position and angle of the teeth, each tooth was need to move to the ideal position on the dental arch curve. However, the teeth will collide with each other in the process of moving the teeth. In order to solve this problem, bounding box was used in this paper[7]. The basic idea of the bounding box technique is to enclose a complex geometric object in a virtual scene with a simple geometric shape (that is, a bounding box), which can be increasingly approached to a real object by constructing a tree structure [8]. AABB (Axis-Aligned Bounding Boxes) is the bounding box along the coordinate axis and the geometric object contained is the smallest hexahedron whose sides are parallel to the coordinate axis. During constructing, the maximum and minimum values in the X, Y, and Z directions of the coordinate axes can be obtained according to the shape of the object to determine the highest and lowest boundary points of the bounding box [9], which can be expressed as:

\[
R = \{(x, y, z) | a_x \leq x \leq b_x, a_y \leq y \leq b_y, a_z \leq z \leq b_z \}
\]  

Where, \(a_x, b_x, a_y, b_y, a_z, b_z\) represent the minimum and maximum coordinates projected by AABB on X, Y and Z axes respectively.

### 3.2.4. Tooth movement

After the position and angle of the tooth on the arch curve are obtained, the next step is to move the tooth. In the tooth position coordinate system, when the tooth is moved, the tooth will have a certain distance compensation in the z-axis direction. Let the distance compensation in the Z-axis direction be \(Z_i\), then the translation coordinate of the tooth is \((X_i, Y_i, Z_i)\), and its transformation matrix is \(T_1\), then:

\[
T_1 = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
X_i & Y_i & Z_i & 1
\end{bmatrix}
\]  

According to the teeth arrangement rule, let the rotation angle of the tooth around X, Y and Z axes during its movement be \(a_x, b_y, c_z\) respectively, then the corresponding rotation transformation matrix is:
In the process of moving the tooth to the ideal position on the arch curve, the final translational rotation of the tooth in the tooth reference coordinate system is:

$$ T = T_3 T_2 T_1 $$

### 3.3. Implementation of tooth arrangement algorithm

The flow chart of the tooth arrangement algorithm is shown in Figure 8:

**Figure 8. Flow chart of tooth arrangement algorithm**

Figure 9 shows the effect of the tooth arrangement algorithm.

**Figure 9. The comparison of the teeth before and after the implementation of the tooth arrangement algorithm**

### 4. Establishment of bracket model library

For the establishment of the standard bracket database, we first need to carry out three-dimensional scanning on the physical model of the standard bracket provided by the hospital to generate point cloud data, and then reconstruct the geometric model to generate a three-dimensional model [10] to establish the bracket model database. Figure 10 shows the model library of orthodontic bracket established in the software system. Figure 11 shows the effect of importing a single bracket into the software system.
5. Conclusions
In this paper, a software system of dental orthodontic robot is developed by using Blender's secondary development technology. This software system can simulate the process of orthodontic process and design orthodontic brackets suitable for patients with dentition malformation. The software system is simple and easy to use, and the user can easily get started. The development and implementation of the software system solves the difficulties of traditional orthodontic surgery in the past and has made certain contributions to the domestic dental repair assistant software system.

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