Orthodontic path planning method based on optimized artificial bee colony algorithm

Zhanli Li, Tongxin Liu*, Hong-an Li, Zhihao Sun

College of Computer Science and Technology, Xi’an University of Science and Technology, Xi’an Shaanxi 710054, China

*Corresponding author’s e-mail: liutongxinjob@163.com

Abstract. Aiming at the orthodontic path planning problems, for example, the number is estimated by orthodontists based on experience, and the efficiency of tooth movement path planning on computer is low. This paper proposed a teeth movement path planning method based optimized artificial bee colony algorithm (ABC). At first, according to the age and gender of patients, the constraint amount of tooth movement is automatically determined. Second, by optimizing the observation bees select method, using both roulette and anti-roulette mechanisms replaced roulette mechanisms, this method can avoid the population from falling into local optimality and obtain better distribution. Then, the initial stage number is obtained through interpolation, and combined with the initial food source generation strategy in ABC. Finally, this paper uses the optimized ABC to plan the teeth movement path and obtain the actual amount of orthodontic stages. The experimental result shows that the optimized ABC has better distribution than basic ABC, and the proposed method is closer to clinical orthodontic, reduced the workload of the orthodontist. The data shows this method is more suitable for different patient situations, reduced the orthodontic stage number and the cost of teeth movement effectively.

1. Introduction
With the gradual maturity of 3D printing and computer-aided design technology, invisible orthodontic technology is more and more popular in the process of orthodontic treatment due to its hygiene, convenience, comfort, and aesthetics [1]. In recent years, the two disciplines of computer science and orthodontics have continually merged, the invisible orthodontic system has become a research hotspot. Researchers are committed to formulate the invisible orthodontic schedule automatically [2-5].

In the process of invisible orthodontic, the orthodontist determined the ideal position of the teeth according to the patient’s malocclusion type and requirements, and orthodontist estimated the orthodontic stage quantity according to the patient’s own situation. Then, used the computer to simulate teeth movement, and determines the key intermediate position on the path based on the orthodontic stage quantity. After above steps, orthodontist uses computer to generate the final schedule and shows it to the patient. After the patient agreed, the appliance model will be printed as various stages [6].

There are two critical steps in the process of formulating invisible orthodontic schedule. The first one is the orthodontist to determine the tooth movement step pace according to the patient’s situation and estimate the orthodontic stage quantity. The second is the teeth movement path planning.

With the advancement of computer computing capabilities, researchers have studied out different methods of tooth movement path planning. Li Kangjun [7] proposed an automatic method of teeth
movement path planning based on genetic algorithm. Motohashi [8] implements teeth movement path planning in a manner of dental arch curve traction, but the teeth collision situation is not considered, and the actual effect is unsatisfactory. Yang Guang [9] proposed a method is using the distance of teeth movement and rotation amount as the objective function, and use the A* algorithm to optimize the intermediate position of tooth movement. But the rotation amount of the objective function is not only rotation angle, but also includes the shaft angle and the torque angle. Zhang Xiao [10] proposed a method to obtained the teeth movement path, that is single tooth arrangement and imported collision detection during orthodontic process, but in the actual process is multiple teeth move simultaneously.

Based on the current research progress, this paper proposed a method for tooth movement path planning based on the optimized artificial bee colony algorithm. First, determine the tooth movement constraints automatically according to the patient’s personal situation. The select method of observation bees is optimized, enriched the population diversity. Finally, combined the tooth translation interpolation and rotation interpolation with initial food source generation of ABC, provided excellent initial food source. In the experimental part, the proposed method is confirmed and compared.

2. Problem Description
Orthodontics relies on the mechanism of alveolar bone destruction and regeneration. Teeth grew in alveolar bone and the fangs are surrounded by bones. The actual hardness of the teeth is very high, far exceeding the bones. In the orthodontic process, a constant force applied to teeth, due to the greater hardness of teeth, the force will not cause too much change with teeth, but the stressed alveolar bone will be destroyed and absorbed slowly. After teeth movement, the alveolar bone will rebuild and regenerate. Therefore, the patient's alveolar bone's reconstruction ability must be considered before planning the teeth movement path. The tooth and alveolar bone structure are shown in Figure 1.

2.1. Tooth movement restriction
Above and reference [11-12] shows, orthodontics actually relies on the alveolar bone reconstruction ability. Alveolar bone is characterized by its abundant blood circulation and active metabolism, so its reconstruction ability is strong and this ability goes with human a lifetime. However, with age and gender factors, the reconstruction ability will gradually decrease, so when formulating a treatment plan, the alveolar bone reconstruction ability needs to be considered to determine the limit of the amount of tooth movement at each stage. Reference [13] shows that when the tooth movement quantity is less than alveolar bone reconstruction capacity, the alveolar bone reconstruction speed is consistent with the tooth movement speed.

In stomatology, adolescents (girls in 11-14 years old, boys in 13-15 years old) are in the permanent tooth stage, at this time, the teeth have been replaced and the bones are basically shaped, they have the
best alveolar bone reconstruction ability. As age gradually increases, the reconstruction ability gradually decreases.

According to the experience of orthodontists, the majority patient in orthodontics, women are 11-26 years old and men are 13-26 years old. Adolescents can plan teeth movement according to the constraints that the amount of movement during each treatment phase less than 0.2mm and the rotation angle less than 2°. If the age is more than 15 years old, when the age increases by one year, the movement constraint at each stage is reduced 0.01mm, and the rotation angle is reduced 0.05°. After the permanent tooth period, women's alveolar bone reconstruction ability is weaker than men. The movement constraint of women of the same age should be stronger than men, compared to men, the movement is reduced 0.01mm and the rotation angle is reduced 0.1°. The formula for calculating the tooth movement constraint is as follows.

\[ d_o = 0.2 - (\text{age} - 15) \times 0.01 - 0.01g \]  
\[ \theta_o = 2 \times (\text{age} - 15) \times 0.05 - 0.1g \]  

\( d_o \) in the formula represents movement amount constraint, \( \theta_o \) represents rotation amount constraint, \( \text{age} \) represents the patient's age, \( g \) represents the patient's gender, when the gender is female, \( g = 1 \), when the gender is male, \( g = 0 \).

After determined the amount of tooth movement based on age, teeth movement path can be planned based on the initial and ideal position.

2.2. Objective functions and constraints

2.2.1. Translation and rotation

The teeth quantity after segmentation is supposed by \( n \), each of teeth from the initial position to the final position will form a series of discrete path points \( m \). Each point is the position of the tooth in each orthodontic stage. Tooth movement state can be divided into two respects: translation and rotation.

The final orthodontic schedule of \( n \) teeth is:

\[ X_s = (T_1, T_2, \ldots, T_n) \]  

The movement sequence of the tooth \( i \) is expressed as:

\[ T_i = (x_i, y_i, z_i, \alpha, \beta, \gamma) \]  

\( x, y, z \) represent the translation amount of the tooth \( i \) in three directions in the local coordinate system, \( \alpha, \beta, \gamma \) represent rotation angle, shaft angle and the torque angle.

The final target is to solve the following problems:

\[ \min \{D(X_s), R(X_s)\} \]  

\( D(X_s) \) in the above formula is as shown:

\[ D(X_s) = \sum_{i=1}^{n} \left( \sum_{j=1}^{m} d_{ij} \right) \]  

\( d_{ij} \) represents the amount of translation of tooth \( i \) in stage \( j \).

\[ d_{ij} = \sqrt{(x_{ij} - x_i)^2 + (y_{ij} - y_i)^2 + (z_{ij} - z_i)^2} \]  

\( R(X) \) in formula (5) is as shown:

\[ R(X_s) = \sum_{i=1}^{n} \left( \sum_{j=1}^{m} \delta_{ij} \right) \]  

\( \delta_{ij} \) represents the rotation amount of tooth \( i \) in stage \( j \).

The objective functions that need to be optimized is as shown:

\[ \min(F(X)) = \min(D(X_s)) + \min(R(X_s)) \]
2.2.2. Restrictions

a) Collision detection

In the movement process of teeth, teeth will collide with each other. Therefore, the collision detection of teeth is as follows:

\[
\begin{align*}
    r &= 0, \sum_{j=1}^{n} c_{ij} = 0 \\
    r &= 1, \sum_{j=1}^{n} c_{ij} > 0
\end{align*}
\]  

(10)

\(c_{ij}\) means whether the \(i\)th tooth has a collision with the adjacent tooth in stage \(j\), the default value of \(c_{ij}\) is 0, and if detected collision the value is 1. The last tooth does not need to be detected, so in the worst case, only the \(n-1\) teeth needs to be detected. \(r\) means whether there is a collision in this movement path, and when \(r=1\), means there was a collision.

b) Amount of translation and rotation

In orthodontics, the amount of tooth translation and rotation cannot be too large, and must fit patient’s situation.

\[
\begin{align*}
    d_0 - d_o &\leq 0 \\
    \theta_0 - \theta_o &\leq 0
\end{align*}
\]  

(11)(12)

\(d_o\) and \(\theta_o\) determined by formula (1) and (2).

c) Tooth pitch

The distance between adjacent teeth cannot be too large, and it is generally considered that it cannot exceed 0.5mm.

\[
d_i(t) \leq 0.5
\]  

(13)

\(d_i(t)\) is the distance from tooth \(i\) to tooth \(i+1\).

3. Artificial bee colony algorithm

In order to solve the multivariate function optimization problem, Karaboga [14] proposed the artificial bee colony algorithm model in 2005. The artificial bee colony algorithm is an optimization method proposed by imitating the behavior of bees. It is a specific application of the clusters intelligent thought. Its main feature is that it does not need to understand the special information of the problem, it only needs to compare the advantages and disadvantages of the problem. Local optimization behavior of individual different labor worker bees eventually makes the global optimal value emerge in the group, and has a faster convergence speed.

The ABC algorithm includes employed bees and non-employed bees, employed bees correspond to food sources, and non-employed bees include observation bees and detective bees. A food source represents a viable solution to the problem, and the nectar volume from the food source represents the objective function value. There is a one-to-one correspondence between the employed bee and the food source. Observation bees choose better food sources based on nectar volume according to a certain probability, the selection method is similar to employed bees strategy. If exceed the limit of selection times (\(limit\)), the food source also cannot update, the food source will be excluded, and the corresponding employed bee will become a scout bee to search a new food source. When the scout bee found food source, the scout bee will change to an employed bee. Since the artificial bee colony algorithm was proposed, it has been adopted by many researchers because of its few parameters and strong adaptability, and it is widely used in the field of optimization [15-16].
3.1. Initialization
The process of initialization is to obtain the initial food source location, \( NP \) is the food source quantity, the quantity of scout bees and observation bees is \( SN = NP/2 \), \( x_i (i \in [1, SN]) \) is the position of the \( i \)th food source, the method of initialization is as follows:
\[
x_i = rand(0,1) \times (ub_j - lb_j) + lb_j
\]
(14)
\( rand(0,1) \) is a random number between 0 to 1, \( ub_j \) and \( lb_j \) is the upper and lower bounds of \( j \)th dimension variable. After the initial food source is generated, the scout bees become employed bees.

Employed bees calculate the fitness for each initial food source, record its fitness value as \( \text{BestFit} \), and record the best food source as \( x_{best} \). Finally, employed bees initialize the current food source mining frequency variable \( \text{trial}(i) = 0 \). The food source fitness function is as follows:
\[
\text{fitness}(x) = \begin{cases} 
\frac{1}{1 + f(x)}, & f(x) > 0, \\
1 + |f(x)|, & f(x) \leq 0 
\end{cases}
\]
(15)

3.2. Search strategy of employed bees
Each employed bee searches for new food sources in its neighborhood, the search strategy is:
\[
x_k = x_i + rand(-1,1) \times (x_y - x_i)
\]
(16)
\( x_k \) is an arbitrary food source different from \( x_i \).
\[
x_i = \begin{cases} 
x_y, & \text{fitness}(v_i) > \text{fitness}(x_i) \\
x_i, & \text{fitness}(v_i) \leq \text{fitness}(x_i)
\end{cases}
\]
(17)
If the fitness value of \( x_i \) is higher than the fitness value of \( x_y \) the \( i \)th hired bee keeps the current food source, \( \text{trial}(i) = \text{trial}(i) + 1 \), otherwise chooses this new food source and discards the current food source and set \( \text{trial}(i) = 0 \).

3.3. Selection strategy of observation bees
The employed bee passes the food source information to the observation bee. The observation bee calculates the following probability \( p_i \) of each food source based on the food source fitness:
\[
p_i = \frac{\text{fitness}(x_i)}{\sum_{i=1}^{SN} \text{fit}(x_i)}
\]
(18)
After obtaining the following probability, the roulette mechanism is used by observation bees to determine whether the current food source is updated according to the following probability. If the update is needed, the new food source is searched locally according to the employed bee strategy.

3.4. Search strategy of scout bees
Scout bees determine the value of \( \text{trial}(i) \) with the current food source. When \( \text{trial}(i) > \text{limit} \), a new food source is searched globally to replace the current depleted food source according to formula (14).

3.5. Record the best food sources
The variable \( \text{MaxFit} \) was used to record the maximum fitness in the current colony, and was compared with \( \text{BestFit} \) for updating.
\[
\text{BestFit} = \begin{cases} 
\text{MaxFit}, & \text{MaxFit} > \text{BestFit} \\
\text{BestFit}, & \text{MaxFit} \leq \text{BestFit}
\end{cases}
\]
(19)
If the best food source is updated, the best food source record \( x_{new} \) in the population is updated synchronously.
4. Optimized ABC and application

4.1. Initial food source generation with tooth movement path planning

In artificial colony algorithm, the initialization phase is generated by scout bees global initial food source. In tooth movement path planning problem, the optimal path is directly from the starting position to the target position, but this is the ideal path without collision. In actual orthodontic process, there will face the problem such as a collision between the teeth, constraints of teeth movement, and exercise restraint, so we need on the basis of the ideal path optimization without collision, fit the path constraint to optimize the path. Based on this feature, the ideal tooth path was firstly obtained and used as the initial food source, and then the ABC was used to optimize the path.

4.1.1. Rotation interpolation

In general, the quaternion linear interpolation function is:

$$
\mathbf{r} = \mathbf{p}_i + (\mathbf{p}_f - \mathbf{p}_i) t
$$

(20)

In the above formula, \( t \in [0,1] \), represents position of interpolation vector \( \mathbf{r} \) on chord \( \mathbf{p}_i \mathbf{p}_f \). As shown in Figure 2, if \( t \) equals 1/4, 2/4, 3/4, divide the chord \( \mathbf{p}_i \mathbf{p}_f \) into 4 equal parts. However, the corresponding arc lengths are not equal, which means that when the uniform velocity changing, the vector angular velocity representing the position of the tooth is not constant, but the tooth angular velocity is constant during the tooth movement path planning process. To solve this problem, used spherical linear interpolation (Slerp) in this paper, as shown in Figure 3. The formula is as shown:

$$
\text{Slerp}(\mathbf{p}_i, \mathbf{p}_f, t) = \frac{\sin[(1-t)\beta]}{\sin \beta} \mathbf{p}_i + \sin t \beta \mathbf{p}_f
$$

(21)

\( \theta \) is the angle between \( \mathbf{p}_i \) and \( \mathbf{p}_f \), \( t\theta \) is the angle between \( \mathbf{r} \) and \( \mathbf{p}_i \), \( (1-t)\theta \) is the angle between \( \mathbf{p}_f \) and \( \mathbf{r} \).

4.1.2. Translation interpolation

In Euclidean space, the shortest distance between two points is the straight-line distance between the two points. Teeth translation only needs to be uniformly interpolated according to the movement constraint. As shown in Figure 4.

In Figure 4, \( C_{0i} \) represents the initial position of tooth, \( C_{ni} \) represents the target position of tooth.
4.2. Parallel selection strategy of observation bees
Observation bees selection strategy in basic ABC is based on roulette mechanism, according to the employed bees pass the information of food sources, the higher fitness of the food source will have higher probability to be selected, after local optimization is around near the high quality food source, this advantage is able to speed up the convergence, the downside is that easy to make the algorithm premature, and get into a local optimum value. Based on this problem, this paper improved the observation bee selection strategy and proposed a parallel selection method.

The parallel selection strategy uses both roulette and anti-roulette mechanisms. The principle of anti-roulette is: get the reciprocal of the fitness value. When the fitness value is larger, the reciprocal value is smaller, so the food source with smaller fitness value is more likely to be selected.

The new observation bees parallel selection step is as follow:

Step1: Observation bees select a food source $x_i$ from the current food source according to the roulette mechanism, as shown in formula (18).

Step2: Observation bees select a food source $x_j$ from the current food source according to the anti-roulette mechanism, and the selection probability of the anti-roulette is shown as follows:

$$p_j = \frac{1}{\sum_{j=1}^{SN} 1/\text{fitness}(x_j)}$$

Step3: The observation bees updated the food source $x_i$ and $x_j$ respectively.

4.3. Actual amount of orthodontic stages
In section 4.1, the orthodontic stage quantity is considered in the collision-free orthodontic environment, but in the actual orthodontic process, the teeth movement will collide. So compared to the ideal situation, the path point quantity in the planning process is bigger, and the actual orthodontic stage quantity will be bigger than the ideal situation.

To solve this problem, this paper proposed a method to get the actual amount of orthodontic stages. When calculating the fitness function by employed bees, the tooth movement and rotation constraints are not considered. After the all planning process completed, the path points of each stage are divided into several according to the translation and rotation constraints, and get the actual orthodontic stage quantity under real conditions.

4.4. Teeth movement path planning steps
Input: Teeth initial posture sequence $P_0$ and target posture sequence $P_m$;
Output: The key intermediate posture sequence $P_{Ai}$ of each tooth;

Step1: Use Slerp spherical interpolation and translation interpolation were used to generate translation interpolation $C_{i} \sim C_{(i+1)}$ and rotation interpolation $\delta_{i} \sim \delta_{(i+1)}$ for each tooth;

Step2: Traverse teeth and plan the tooth movement path;

Step3: Initialization parameters mainly include the number of path points $m$, the maximum limit parameter limit for each food source search, the current iteration number $iter=0$, the maximum search number of scout bees $MaxLoop$, the initial population number $NP$, scout bees and observation bees respectively $SN=NP/2$, and the external storage $PA_i$;

Step4: The scout bee algorithm generates an initial number of $SN$ food sources, which are then converted into hired bees;

Step5: The scout bee algorithm generates an initial number of $SN$ food sources, which are then converted into hired bees;

Step6: Employed bees search new food sources and calculate the fitness, if the new one is better, then update the food source position, and set $trial(i)=0$, update $PA_i$. Otherwise, $trial(i)$ will increase by 1, update $PA_i$;
Step7: Observation bees calculate the following probability in parallel based on the fitness based on roulette and anti-roulette mechanism, and then search for new food sources according to the following probability respectively, and then turn into hired bees to conduct local search, calculate the fitness, judge whether to update, and update the mining times trial(i), update PAi. If trial(i)>limit, skip to Step8, otherwise, skip to Step9;

Step8: Abandon the current food source and turn it into the scout bee, generate new food source randomly in the decision space, calculate the fitness and update trial(i);

Step9: Record the food source and update PAi, number of iterations iter=iter+1, if iter>MaxLoop, output PAi, otherwise skip to Step7.

5. Experiment and analysis

5.1. Optimized ABC performance test
In order to verify the improvement of population diversity of the improved ABC proposed in this paper, in this experiment, the following two benchmark test functions are used to test the optimized ABC and the basic ABC:

(1) Sphere

\[ f_i(x) = \sum_{i=1}^{n} x_i^2 \]  

In the above formula, \( x_i \in [-100,100] \), when \( x_i = (0,...,0), i=(1,...,n) \), the function gets the global minimum \( f_i(x) = 0 \).

(2) Griewank

\[ f_2(x) = \frac{1}{4000} \sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} \cos \left( \frac{x_i}{\sqrt{i}} \right) + 1 \]  

In the above formula, \( x_i \in [-600,600] \), when \( x_i = (0,...,0), i=(1,...,n) \), the function gets the global optimal value \( f_2(x) = 0 \).

Figure 5. The individual distribution of the basic ABC algorithm
In the experiment, the population size $NP$ was set to 40, the number of food source $SP$ was set to 20, search limit was 200, $MaxLoop$ was set to 1000. Figure 5 and Figure 6 separately delineated the individual distribution of basic ABC and optimized ABC during the same search period. As you can see from the graph, for both unimodal function $f_1(x)$ and multimodal function $f_2(x)$, compared with the basic ABC algorithm, the individual value of optimized ABC is more accurate and scattered.

5.2. Optimized ABC validity test

The experiment is Intel i7 3.20GHz CPU computer, Windows 10 operating system, Visual Studio 2015 development platform, and VTK toolkit. The tooth movements described above are achieved under the environment of Udesign, a proprietary dental software. The teeth data are provided by Ulab.

5.2.1. Number of orthodontic stages

In this section, the teeth data of 10 normal patients are selected as an example. Patients with extraction and expansion are not considered. The results of the algorithm planning in this paper are shown and compared with the data obtained by orthodontist based on experience. The result is shown in Table.1.

From Table 1, it can be seen that the actual orthodontic stage quantity planned by new method is less than the quantity estimated by the orthodontist, and also less than the quantity planned by basic ABC. It can be seen that the method of this paper obtained tooth movement constraint can make the orthodontic schedule more accurately. The method proposed in this paper can replace part of the orthodontist's workload for normal orthodontic patients, realized automation.

| Number | Age | Gender | orthodontist | ABC | Optimized ABC |
|--------|-----|--------|--------------|-----|---------------|
| 1      | 24  | Male   | 54           | 61  | 52            |
| 2      | 16  | Male   | 43           | 42  | 40            |
| 3      | 14  | Male   | 39           | 41  | 39            |
| 4      | 17  | Male   | 43           | 43  | 41            |
| 5      | 19  | Male   | 45           | 49  | 45            |
| 6      | 21  | Female | 56           | 50  | 53            |
| 7      | 18  | Female | 51           | 46  | 47            |
| 8      | 20  | Female | 47           | 49  | 47            |
| 9      | 13  | Female | 38           | 36  | 33            |
| 10     | 21  | Female | 59           | 61  | 48            |

5.2.2. Results comparison and analysis

This paper selected a set of teeth data as an example. The orthodontic schedule generated by the optimized ABC algorithm is shown as Figure 7, and the comparison of the initial and final position after teeth movement is shown as Figure 8.
As shown in Figure 7, the upper jaw is taken as an example, the patient is a 14 years old boy, and it is divided into 39 stages. Parameter \textit{limit} is set to 100 times, \textit{MaxLoop} set to 4000 times, and the population size is 40. Nine intermediate stages is selected to show the result. The line segments on the teeth in the Figure 7 are the characteristic line segments of each tooth. It can be seen that after 39 stages of translation and rotation, each tooth gradually moves to the ideal arch line, and the tooth characteristic line segments also gradually smooth (such as the teeth marked by oval and rectangular).

Figure 8 shows the position change of each tooth. It can be seen that the right side of the maxillary incisor (tooth number 21) has a large rotation amount, the rotation angle is 18.9°, and the front molars (tooth number 14, 24) on both sides have a large movement volume, which are 2.393 mm and 2.418mm. For the sample data, the primary movements are concentrated in the anterior, canines and premolars teeth, the posterior molars on both sides move less. It is difficult to correct the posterior molars in actual orthodontic treatment.

As shown in Table 2, the basic ABC’s convergence speed is slow, and the teeth movement cost is large. After optimized the select method of the observation bee, the basic ABC algorithm used 38s to plan the tooth movement path, and the optimized algorithm takes 22s. Total teeth movement volumes are smaller, the orthodontic stage quantity is less, and the convergence speed is greatly improved. It can be seen that optimized ABC has faster convergence speed, lower teeth movement cost, and better distribution, can reduce patient burden effectively.

### 6. Conclusion

Aiming at the shortcomings in the process of the traditional invisible orthodontic schedule planning, this paper proposed to determine the tooth movement constraints dynamically according to the

| Table 2. Translation volume and rotate angle of teeth |
|-----------------------------------------------|
| unit/total offset | ABC | Optimized ABC |
| \(\Delta x\) (mm) | 25.508 | 22.186 |
| \(\Delta y\) (mm) | 17.631 | 16.235 |
| \(\Delta z\) (mm) | 8.634 | 6.268 |
| \(\Delta \alpha\) (°) | 35.199 | 31.523 |
| \(\Delta \beta\) (°) | 41.644 | 39.395 |
| \(\Delta \gamma\) (°) | 16.235 | 13.173 |
| Stage quantity | 43 | 39 |
| Operation time (s) | 38 | 22 |

As shown in Table 2, the basic ABC’s convergence speed is slow, and the teeth movement cost is large. After optimized the select method of the observation bee, the basic ABC algorithm used 38s to plan the tooth movement path, and the optimized algorithm takes 22s. Total teeth movement volumes are smaller, the orthodontic stage quantity is less, and the convergence speed is greatly improved. It can be seen that optimized ABC has faster convergence speed, lower teeth movement cost, and better distribution, can reduce patient burden effectively.
alveolar bone reconstruction ability, with which reduces the workload of the orthodontist. Then optimized the artificial bee colony algorithm. Improved the method of observation bee select food source which accelerates the convergence speed and avoided the problem of falling into the local optimal value. This paper combined the tooth translation interpolation and rotation interpolation with initial food source generation of ABC. Finally, the optimized ABC is used to plan the tooth movement path and obtain the actual orthodontic stage quantity according to the constraint volume. At last, the test was performed in simulation software, and the actual orthodontic stage quantity was compared with the value estimated by the orthodontist. The results show method of this paper can plan a less stage quantity of orthodontic schedule. The results of path planning are compared with the results of basic ABC, the results show that optimized method can generate higher-accuracy movement path faster, reduce the total movement volumes of teeth, shorten the orthodontic time effectively, save patient’s costs, and has practical significance.

Acknowledgments
This work is partially supported by the Natural Science Basic Research Plan in Shaanxi Province of China (2019JM-162) and the Doctoral Research Startup Foundation of Xi’an University of Science and Technology (2019QJD007). We declare that there is no conflict of interests regarding the publication of this article and would like to thank the anonymous reviewers for their valuable comments and suggestions.

References
[1] Lu H, Kang N. (2019) Research progress and current situation of influence of Invisalign system and fixed appliances on periodontal health. Journal of Oral Science Research, 35(7): 625-628.
[2] Fan R, Niu Y and Jin X. (2013) Computer aided invisible orthodontic treatment system. Journal of Computer-Aided Design & Computer Graphics, 25(1): 81-92.
[3] Kumar Y, Janardan R, Larson B. (2013) Automatic virtual alignment of dental arches in orthodontics. Computer-Aided Design and Applications, 10(3): 371-398.
[4] Cho M, Choi J and Lee S. (2010) Three-dimensional analysis of the tooth movement and arch dimension changes in Class I malocclusions treated with first premolar extractions: A guideline for virtual treatment planning. American Journal of Orthodontics and Dentofacial Orthopedics, 138(6): 747-757.
[5] Zhang Y, Zhao Z and Lu P. (2002) Robotic system approach for complete denture manufacturing. IEEE/ASME Transactions on Mechatronics, 7(3): 392-396.
[6] Gerard Bradley T, Teske L and Eliades G. (2016) Do the mechanical and chemical properties of Invisalign appliances change after use? A retrieval analysis. Eur J Orthodontic, 38(1): 27-31.
[7] Wang X, Li Z and Ma Y. (2012) Method of arranging teeth automatically based on PSO. Computer Engineering and Applications, 48(5): 211-212.
[8] Nobuyoshi M. (1999) A 3D computer-aided design system applied to diagnosis and treatment planning in orthodontics and orthognathic surgery. European Journal of Orthodontics, 21: 263-274.
[9] Yang G, Li Z. (2011) Research on Simulation and Optimization Method for Tooth Movement in Virtual Orthodontics. Xi’an University of Science and Technology.
[10] Zhang X. (2016) Research on teeth orthodontic movement path planning and visual development. Shan Dong University.
[11] Yasuko M.K, Toru K, and Keita M. (2007) Histomorphometric study on the effects of age on orthodontic tooth movement and alveolar bone turnover in rats. European Journal of Oral Sciences,115(2).
[12] Hu Z, Liu C and Zhou Q. (2016) Age - related changes of posterior alveolar bone height of maxilla in Chinese population. Chinese Journal of Conservative Dentistry, 12.
[13] Liu Y, Jiang J, Zhang H. (2007) Long-term remodeling of anterior alveolar bone from treatment to retention. Journal of Practical Stomatology, 11,23-6.

[14] Karaboga D. (2005) An idea based on honey bee swarm for numerical optimization. Technical Report-TR06.