A System for Simulating the Orthodontic Treatment Plan

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ABSTRACT:

A computerized system is built to help orthodontist in planning the treatment procedures of craniofacial deformities. CT scans (head) for 10 patients were processed and their three-dimensional reconstructions were developed. For each patient a profile representing the present state is obtained. Another predicted profile for the patient drawn and the orthodontic formulates his plan depending on the distance measured between the two profiles. The system provides a new method for segmentation and visualization of the teeth crowns and roots. The three axes of each tooth were computed to enable the translation and rotation.

Keywords—*orthodontics, craniofacial deformities, three-dimensional reconstruction, segmentation, visualization.*

I INTRODUCTION:

Treatment of malocclusions (improper bites that may be a result of tooth irregularity, disproportionate jaw relationships, or both) is a complex task that requires careful pre-treatment planning [1]. The studies of this dental problem were limited to traditional two-dimensional analysis from orthopantomograms, intra-oral X-rays or cephalometric [2].To establish this system,a volumetric data set was prepared for each patient using the marching cubes algorithm [3]. First threshold values specified by obtain the minimum and maximum intensity. A surface rendered was applied on the data set to generate an iso-surface. Then a smoothing filter is used to adjust point coordinates using Laplacian smoothing. The effect is to smooth the mesh, making the cells better shaped and the vertices more evenly distributed. Surface rendering is used to represent each anatomical component such as bone and teeth.

The linear spline curve interpolation [4] is used to draw the profile curve. Profile was drawn by using boundary detection algorithm [5]. A new profile achieved by make the orthodontist mark two points that satisfy the shape of the profile curve and depending on the shape of the new profile the orthodontist takes his decision about the treatment. The orthodontist aims to

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achieve two targets the first one providing the functionality of the patient teeth by improved the bite (*occlusion*)the second one improving the general appearance of patient's teeth and face. Depending on the distance measured between the two profiles (real/virtual) the orthodontic decide the treatment used to achieve the best result. In case the distance measured between two profiles is very small ("fixed multi-bracket therapy is used") In this case orthodontic wires are inserted into dental bracesto fix the distance between teethas shown in Fig 1, 2. In case of the distance measured is large then the Removal ("extraction") of teeth to create more space have to be done and in case the distance measured is too large ("severe cases") surgery may be necessary to improve the patient looks.

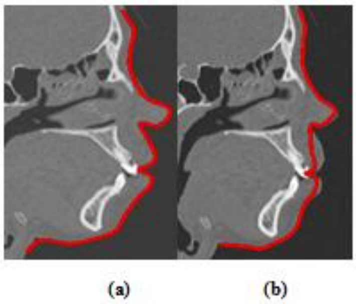

Fig 1 Two profile (a) the real profile and (b) virtual profile

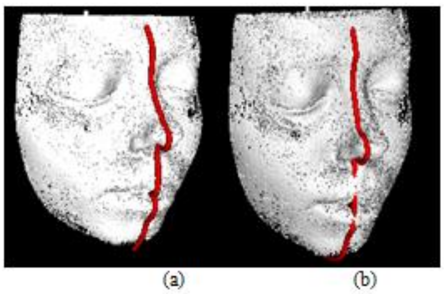

Fig 2 Two profiles after 3D reconstruction (a) real profile (b) virtual profile shows that the upper limps come out from the virtual profile curve

In case of overcrowding of the teeth the orthodontist needs to apply space analysis technique for taking any decision to detect which tooth or molar will be removed or extracted. Subsequently, it was necessary to investigate a procedure for extraction simulation operation to help the orthodontic in decision-making and visualize the treatment plane. A new method for segmentation and visualization of teeth crowns and roots, the simulation of the teeth extraction operation and adjustment the teeth that need fine adjustment will be introduced.

II MATERIAL AND METHODS:

Purpose of this study is to develop a computerized system to establish a virtual reality environment for orthodontic treatment. The system is designed to meet specific requirements for treatment planning of teeth deformities and it's provides the followings tool:

- A Tool for segmentation and visualization of the teeth crowns and roots based on CT scan of the lower jaw.

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- A Tool to compute the axis of each individual tooth
- A clear visualization for the patient profile before and after the treatment.
- A user-friendly environment that could be used easily by the orthodontists as shown in Fig 3.

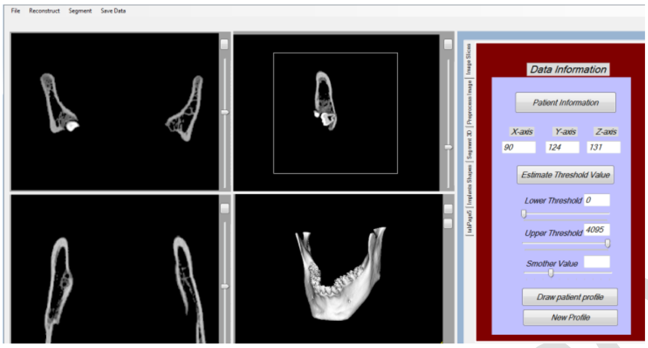

Fig 3 Graphical user interface for the Program

2.1 Teeth Segmentation Using Combined Threshold Technique-Connected Component Algorithm.

Segmentation of teeth crowns and roots include the following three steps. The first step, obtain the mandible data of the patient after segmentation from the 3D patient skull model by using algorithm [6] as shown in Fig 4. The second step is to apply segmentation technique (connected component) to segment the mandible data to separate the lower teeth. The last step is to apply another segmentation technique (combine of K-mean, labeling and connectivity algorithm) to separate each tooth. Then using vtk function "vtk property" to change the color for each tooth to recognize each tooth., each tooth recognize will be saved as a STL file (sterolithography).

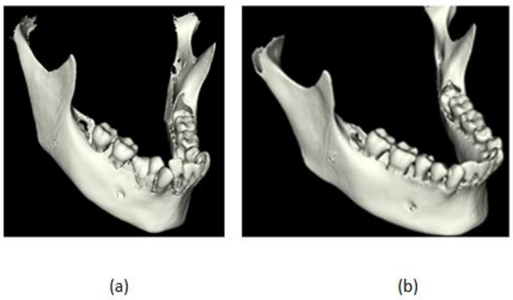

Fig 4 Segmented mandibles from the CT-scans (a) first case (b) second case

The teeth main parts are crowns and roots, each part has its own gray level (intensity), with studying x-ray imaging, it was found that teeth enamel (hardest area covered the teeth crown) showed the highest intensity in the image of the skull volume. In addition, the roots showed intensity equal to or higher than the intensity of the bone as it connected with the bone of the jaw. So that the Segmentation process that used to separate the teeth from the mandible, data involves two steps. The first step is to segment the crowns of the teeth. The second step is to segment the roots. While the teeth enamel have the maximum intensity gray level in the image. Then its pixels are automatically extracted from 3D data matrix of the mandible using threshold segmentation technique. First, the teeth intensity value (maximum intensity) given to the algorithm. Then an empty 3D matrix with the same size of the mandible matrix is created, this matrix is called the teeth matrix. In the next step, the algorithm checks whether the intensity of every pixel in the mandible matrix is equal to predefined teeth intensity threshold or not. Then the extracted pixels that verify the condition will be transferred to the empty teeth matrix in their corresponding positions. This pixel represents the teeth enamel show Fig 5.

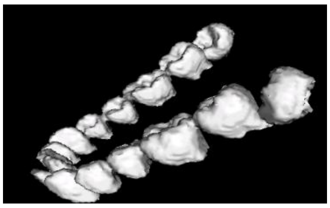

Fig 5 Crown Segmentation

Pixels of the teeth crown used to complete segmentation for the roots. By check the connectivity for each pixel in the mandible data with the crown pixel in the teeth data. For any pixel P in the slice Z there were twenty-five neighbors in the same slice, in the slice Z-1 and Z+1. By counting, the number of pixels that have maximum intensity (crown pixels) and tested if they are greater than ten pixels then these pixels are from the teeth but if they are not then the pixel from the mandible data.There are some variables that would be chosen to enhance result of segmentation; the first one is to choose the teeth threshold values to be higher than the bone value (the teeth shows higher intensity in CT scans). The second variable is the number of pixels satisfying maximum intensity in the neighborhood, best results is obtained at eight pixels (16% of the total number of pixels in the neighborhood). The results from applying the segmentation technique to this case are shown in the Fig 6

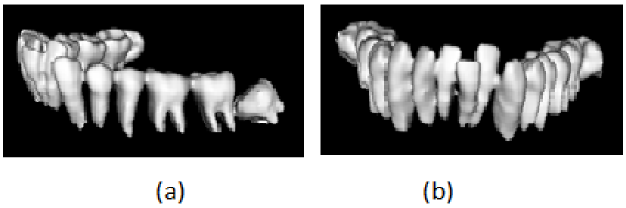

Fig 6: lower segmented teeth (a) Left side for the complete mandible teeth (b) front sides for the complete mandible Teeth.

2.2 Individual tooth segmentation in the mandible using k-means clustering and connected component algorithm.

The **k-means algorithm** is an algorithm to cluster objects based on attributes into k partitions [7].The initial step of the k-mean algorithm is to choose a set of K instances as centres of the clusters. Next, the algorithm considers each instance and assigns it to the closet cluster. The cluster centroids are recalculated after each instance assignment. This process is iterated until the centroids position not changed.

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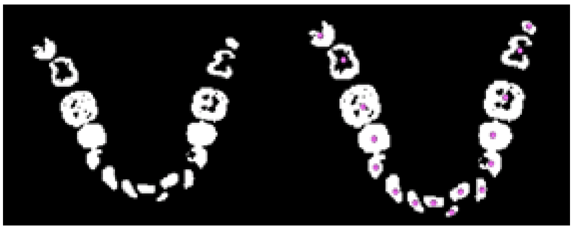
2.2.1 First Approach to segment individual tooth

There are 16 permanent tooth in the mandible (lower jaw) [8]. To segment each tooth it is considered as a group of pixels. So there will be 16 group of pixels using k-mean clustering each pixel in the teeth matrix will be classified to a specific group. To apply k-mean algorithm, first assign for each group a centroid chosen a starting slice, so 16 point will be appear clearly as shown in Fig 7. The algorithm checks each pixel in the starting slice and assigns it to a specific group according to minimum distance measured between it and the chosen centroids.



(a) (b)

Fig 7 Each tooth represent as a separating group (a) starting slide (b) choose a centroid for each group of tooth.

After assigning each pixel to a specific group,centroids are recalculated and pixels are rearranged again. After completing the iteration the classification of 16 groups into 16 tooth end. Segmented tooth will be assigned to a specific graylevel value. Then the slices above and below the starting slice will be classified according to minimum distance measured between each pixel and the final 16 centroid in the staring slice as shown in Fig 8

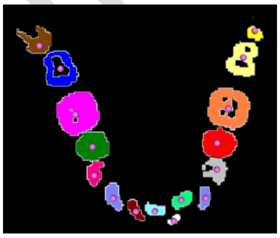


Fig 8 each segmented tooth will be a specific gray level value

2.2.2 Second approach to segment individual Tooth:

The Previous method didn't achieve complete segmentation for the pixels of the slice bellow the starting slice as the teeth crowns are straight once the slice below the starting slice the roots appears oblique these slices we hard to be segmented or classified shown in Fig 9. Also this method shows an error in segmentation of the teeth that is not parallel to x-y plane as there many cases open there mouth while scanning as shown in Fig 10.

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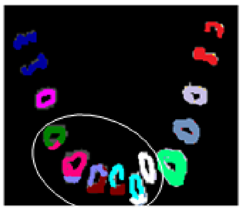

Fig 9 Applying K-mean algorithm to all slides produces an error in the slides that below the starting slides because of the teeth roots inclined

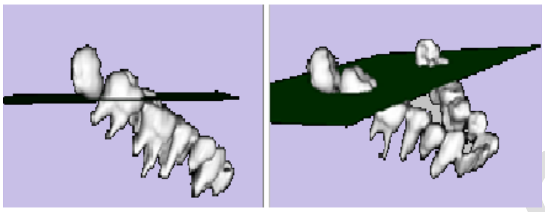

Fig 10 Data of lower teeth not parallel with x-y plane

Updating the previous algorithm, the points of centroids will be replaced by straight lines to minimize the error in classifying each pixel in the teeth roots. The first step is to assign two centroids in two different slices for each group then a straight line will be drawn between these two centroids this line will be considered as a center reference point in each slice. Sixteen lines will be drawn from thirty-two centroids. Assume P1(x_1, y_1, z_1) is the first point and P2(x_2, y_2, z_2) is the second point. The equation of the line that pass through two points (P1(x_1,y_1,z_1) and P2(x_2,y_2,z_2)) is given by eq1. The algorithm checks each pixel in the teeth matrix and measures the distance d between each pixel P and the sixteen lines and assign it to its group according to minimum distance measured.

$$\frac{x - x1}{x2 - x1} = \frac{y - y1}{y2 - y1} = \frac{z - z1}{z2 - z1} \qquad (1)$$

Where X, Y, Z pixelP, X1, Y1, Z1 first point and X2,Y2,Z2 the second point of the line passes through teeth .

The minimum distance between pixel P(X, Y, Z) and the line drawn between two centroids is the length of the perpendicular line that drawn from point P to the line as shown in Fig11. Assume point E is a projection of point p on the line P1, P2 then the length of the perpendicular line PE obtain from eq2.

$$d = \|\overline{PE}\| = \frac{\|\overline{PP1} X \overline{PP2}\|}{\|\overline{PP2}\|} \qquad (2)$$

Where: PE is the length of the vector PE, line vector PP1, PP2 and P1P2.

This approach shows good segmentation of each tooth except for the disadvantage that it is hard to the user to click thirty-two points on the screen to identify each tooth and needs complex calculations. So this method is updating by using connectivity algorithm.

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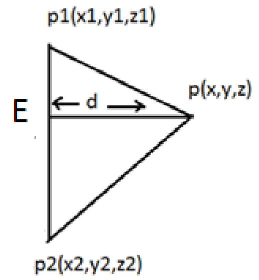


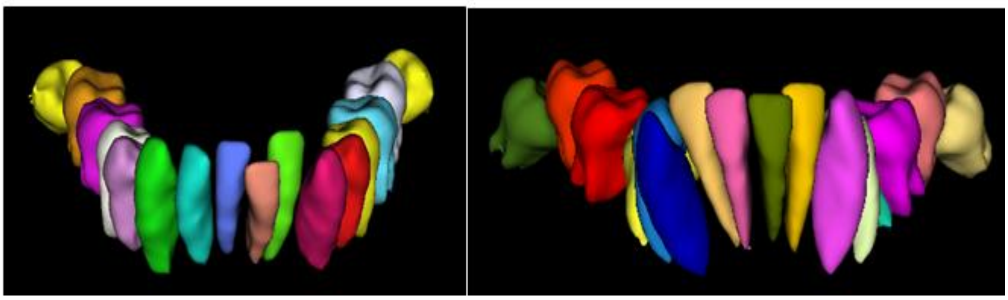
Fig 11 Distance d between the line and point P

2.2.3 Third approach for segment the individual tooth.

Using combining connected component and k-mean clustering algorithm to segment each tooth. First step assign starting centroids for each tooth in selected slices where the section of the tooth appears round. Second step, the pixels in the slices upward and downward the starting slice classified by using connectivity algorithm as follows

1- Each pixel P in a certain slice (Z+1) have twenty five neighbors in the slice Z (starting slice).
2- Checking the gray level of each pixel new centroids is assigned according to the value of the majority of pixels.

After completing the scanning for all pixels in all slices then each tooth is obtained with a specific gray level value. Results from applying third approach it was found that the optimum segmentation method used to segment each tooth is the combination of K-mean algorithm as shown in Fig 12.Each individual tooth as shown in Fig 13 is rendered separately in three dimensions to help orthodontics to observe the deformation that may be found in the arch.



(a) (b)

Fig 12 complete segmentation for each individual tooth (a) segmented tooth for case1 (b) segmented tooth for case 2

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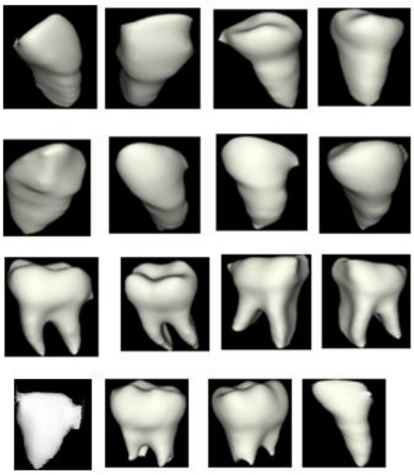

Fig 13 Each Tooth and Molar of the Lower Teeth

2.3 Compute three axes for each tooth

After separation of each tooth its reference longitudinal, bucco-ligual and mesiodistal axes were determined. Then draw spline curve to connect centroids points. This curve represented the Angle's line of occlusions.

2.3.1 Computation of Longitudinal axis of each tooth

Compute longitudinal axis of each tooth. Each tooth was divided into two parts. We must select one point in the upper part and one point in the lower part for each tooth "the parts above and below centroids of each tooth". To obtain the lower and upper points in each tooth we must move parallel to the real spline curve and compute mean points in each slice in the image matrix, then we choose the upper and lower points according to the maximum density at each slice upper and lower the spline plane. Longitudinal axes were the lines that passed through these two points. Then a parametric equation applied to obtain the z-axis of each tooth as shown in Fig 14.

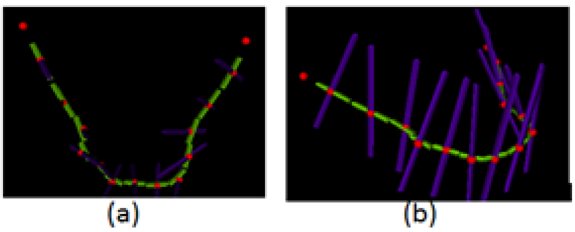

Fig 14 (a) Axial (b) sagittal view for the longitudinal axes each tooth.

2.3.2 Computation of bucco-ligual axis of each tooth

Horizontal axis of each tooth obtained by compute the tangent of spline curve at each tooth as shown in Fig 15.

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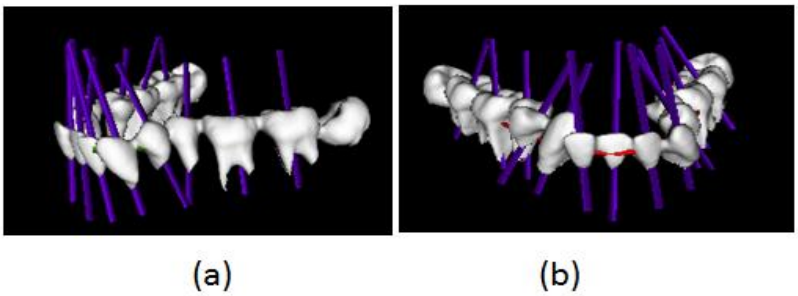

Fig 15bucco-ligual axes for each tooth. (a) Sagittal view and (b) front view

2.3.3 Computation of mesio-distal axis of each tooth

Perpendicular axis of each tooth computed by obtained the cross product between two vectors "bucco-ligual and lonitio-dinal axis" as shown in Fig 16

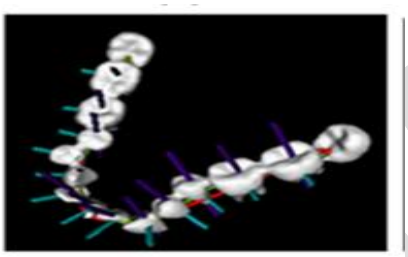

Fig 16 view of mesio-distal axis of each individual tooth

2.4 Simulation of the Extraction Operation:

After teeth segmentation and segmentation of each tooth have been completed. Then the simulation of the extraction operation will be done by obtain the edentulousmandible Adding the well-defined tooth to the edentulousmandible. Then we obtain the mandible with a well-defined tooth. The algorithm will remove the tooth or molar that wanted to be removed. In addition, the rotation and translation done by clicking on the tooth that wanted to be animated as shown in Fig 17.

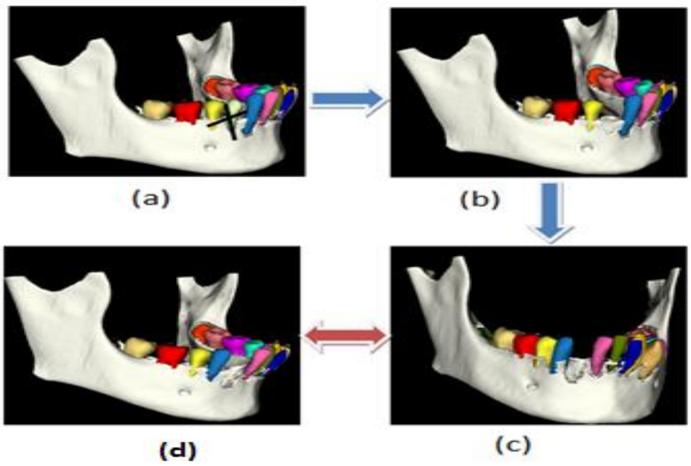

Fig 17 (a) the data set (b) Removal of First Premolar(c) Translation of Right Canine to the canine position (d) the final shape

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3. CONCLUSION:

The development of a computer-aided treatment planning systems is still ongoing work. In addition, the clinical evaluation of the tools that used by the orthodontics is still pending a developed. So we are looking forward to improve the segmentation algorithm that used to segment the lower teeth to sense the difference in gray level between the bone and the teeth to appears more better, modify the segmentation algorithms to applied to maxilla in order to separate each tooth in the upper jaw. This step is very important in order to build an expert system, this expert system helps the orthodontics in taking the decision about the type of the treatment and the tooth or molar that decided to extracted. Making simulated tool to simulate the tools likedental braces and **retainer** and cooperated this tools with the patient model to predict the treatment outcome.

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