Abstract—In the present investigation, positions of head landmarks in panoramic x-ray images in relation to cephalometric landmarks were studied. Special landmarks in right and left sides of mandible were manually identified and calibrated with reference readings. The measured landmarks are compared for both sides with different panoramic duration times. Results between left and right were compared using a thin-plate spline (TPS) geometric tool. The averages of both sides were reported and compared with frontal cephalometric readings. Differences between left and right landmarks were found to be significant in relation to cephalometric landmarks and differences between different duration times.

I. INTRODUCTION

Cephalometric analysis is the study of the dental and skeletal relationships in the head, and involves the calculation of linear distance measurements, angular measurements, area measurements, and ratios [1]. Because shape information cannot be determined from these size-based measurements, geometric morphometric tools need to be employed in the cephalometric analysis of craniofacial morphology. The morphometric method provides a geometric representation for the relative locations of landmarks (LMs), and then establishes an unambiguous one-to-one correspondence between the forms. Furthermore, morphometric techniques allow the integration of the distinct information present in cephalometric analysis such as geometric location and biological homology because any changes in the relative spatial relationship of the LMs due to shape changes.

The use of algebraic measurements in traditional cephalometric analysis is known as conventional cephalometric analysis (CCA). The four parameters employed in CCA are the linear distance measurements between two LMs, the angles calculated from triplicate measurement of LMs, the areas of triangles that can be measured and summed, and the ratios usually of linear distance measurements [1].

The remainder of the paper is organised as follows. Section II shows in details the overall phases of the proposed algorithm. Section III discusses material and methods, and Section IV gives the experimental results. Section V concludes the paper.

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II. PRELIMINARIES

A. Panoramic x-ray imaging

Panoramic radiographs are schemes of a curved image layer, while the panoramic detector (x-ray film) wrapped around the outside of the face, the panoramic radiograph provides a plan of one side, then the midline, then the other side of the face and jaws. This means that the image is formed section by section [2]. It makes a complete half circle from ear to ear to produce a complete two-dimensional representation of all teeth and jaw bones [3].

Panoramic x-ray images are an important tool for the dentist as the give a broad overview of the entire mouth and supply information about teeth, upper and lower jawbone, sinuses, and other hard and soft tissues of the head and neck. The advantage of panoramic x-ray imaging is its ease of use. Unlike other x-ray imaging techniques where the film is placed inside the patient’s mouth, the panoramic film is contained in a machine that moves around the patient’s head [4] (see Fig. 1).

While panoramic x-ray imaging is easy to perform well it is equally easy to perform poorly. Many errors are due to incorrect patient positioning, leading to excessive and sometimes disproportionate distortions [2].

B. Thin Plate Spline (TPS)

The term TPS originally refers to the physical analogy of bending a thin metal plate and was introduced to geometric design by Duchon [5]. A flat metal plate can be represented by 2-dimensional co-ordinates \(x\) and \(y\). A bended metal plate will have a displacement perpendicular to the \(x\) and \(y\) co-ordinates and therefore be represented within a 3-dimensional space \((x, y, z)\).

![Fig. 1 Panoramic scanner machine](image)

The biharmonic equation

\[
\Lambda^2 u = \left( \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right)^2 u = 0
\]

(1)
has a fundamental solution [6,7]

\[ z(x, y) - u(r) = r(x, y)^2 \ln r(x, y) \]  

(2)

where \( z(x, y) \) refers to the displacement orthogonal to the x-y plan. TPS is a process of finding a \( z(x, y) \) function which minimizes the bending energy [6,7]

\[
E(z(x, y)) = \iint \left[ \left( \frac{\partial^2 z(x, y)}{\partial x^2} \right)^2 + 2 \left( \frac{\partial^2 z(x, y)}{\partial x \partial y} \right)^2 + \left( \frac{\partial^2 z(x, y)}{\partial y^2} \right)^2 \right] \, dx \, dy
\]

(3)

In the case of 2-dimensional co-ordinate transformations using TPS, only a 2-dimensional space is used in which the displacement in the z direction is re-interpreted as a displacement in the x and y coordinate.

Fig. 2  Initial thin plate spline mesh.

Fig. 3. Deformed thin plate spline mesh.

III. MATERIALS AND METHODS

Panoramic radiography cases for a 14 years old female are provided by the Tissue Engineering Laboratory (TE-lab) [8,9], where eleven LMs will be taken for different scanned duration times (a weak, a month, three months and six months). Four left LMs and other corresponding right ones are taken in addition to three vertical ones at the centre of the face. The origin will be determined from the vertical LMs for each panoramic case as shown in Fig. 4, the left and right corresponding LMs are compared to each other for the same scanned case based on the origin area as shown in Fig. 5. For all scanned cases, the vertical LMs are used to identify the modification of their positions that may have occurred shown in Fig. 6 which gives the comparison between corresponding LMs with different duration times. All LMs were chosen manually specific to Braces Pty Ltd cephalometric analysis [10], and a TPS landmark analyser used to evaluate the suitable side that can be used for determining the CCA. Fig. 4 shows the panoramic x-ray images with their LMs. The different panoramic x-ray images were taken not only at different times, but also with different patient positions to evaluate the suitable or normal position for any patient to capture the panoramic x-ray images that can be used to determine the CCA.
IV. EXPERIMENTAL RESULTS

The vertical LMs used to determine the origin and evaluate the left and right LMs variance readings and time-position variance readings. However, the variance between each LM at both sides over all the five cases are determined and evaluated to select the suitable panoramic side that mimic the CCA for any time-position deference cases.

For the same panoramic x-ray images, the left LMs are not symmetric to those at right. The plots in Fig. 5 show the noticeable difference between left and right corresponding LMs for the same case based on the origin. For the patient position difference it was observed that the changes at right side LMs are larger than corresponding left side LMs as shown in Fig. 6 where the area of left LMs are changed in a limitation zone referred to the position of patient unlike the right ones. As we noticed by comparing the variance referred to the difference duration time of LM8 and LM10 with LM4 and LM6. The manual selection causes some errors as shown in the reading of LM11 that gave a high error margins. Finally, Fig. 7 shows the origin area based on the three vertical LMs at each panoramic case.
Fig. 6 Comparison between each left and corresponding right LMs with different duration time.

Fig. 7 The origin area based on the three vertical LMs at each panoramic case.

V. CONCLUSIONS AND FUTURE WORKS

In this paper, different LMs are taken for each panoramic x-ray case provided covering both left and right side in addition to the vertical LMs. The experimental results with TPS package, show a significant difference between the left and right LMs used in CCA, and proved that left LMs are more suitable to mimic the CCA than the right LMs based on the panoramic origin, where the variance at panoramic generated due to the time-position deference can be calibrated with the origin. The main disadvantages of this new technique was the manual selection phase that can be calibrated by adding an automated algorithm for the technique to avoid error reflection that may generate unsuitable readings. More cases can be studied on different panoramic cases with challenged time-position types.

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