Establishment of Reference Frame for Sequential Facial Biometrics

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Abstract

Facial biometrics as an objective, accurate, living parts measurement methodology, is widely used in assisting diagnose and treatment plan within the practice of medicine and dentistry. It is particularly popular that the quantification of changes before and after a clinical intervention. However the measurement accuracy of volumetric changes over consecutive 3-D images has remained as a challenge to date. This paper reports one approach that uses the facial features within the facial images as the reference frame for consecutive comparisons, a template of region of interest as a fixed window for volume measurement and a disposable gage for facial posture control, to achieve precise volumetric measurements over consecutive facial scans. The errors of proposed the approach was evaluated and the reproducibility when using such an approach was found less than 1% with a real case.

Introduction

Although quantification of face has been widely applied in medicine (Schwenzer-Zimmerer et al, 2009; Ferrario VF et al, 1999) and dentistry (Sattarzadeh and Lee, 2010; Krimmel M et al, 2006). When assessing changes from a consecutive scan images, it is critical that all of the scan images were in the same reference frame. Two aspects of this issue: firstly, with human body, the shape has evolved and grown to be, which has no readily available datum features, such as a plane or a sphere etc. as a consequently, for the volume measurement, the definition of the volume boundary can be easily deviated.

The reference frame need to serve two purposes: it should be able to identify a unique position in a 3-D space, and it should contain identical features or areas for the two or more surfaces to be able to superimpose precisely. It can be difficult in itself for freeform surfaces, to meet such a criterion for living parts, such as face or other body parts, particularly for young children can be really challenging.

Currently published materials reported to use a mechanical structure to guarantee the positions in three axis as well as rotations (Roth et al, 2012; HeadScanDevice, USA, 2014), although it is evidenced that it can achieve a high repositioning accuracy as less than 0.1mm (Roth et al, 2012), it is not always achievable with human, when a child is only 3 months old, or a fragile elderly patient.

Precise volume measurements rely on a reference frame that defines the same location, position and Region of Interest (ROI) over a sequential scan images. This casts a problem as the head positions and sitting postures of patient are varied between scans/appointments. To obviate this challenge, a reference frame based on the facial features within the facial images was developed to achieve uniformity in the alignment, positioning and a definition of ROI of facial scan images.

Materials and methods

Facial image capture (Facial scan)

3dMD facial scanning system is designed to be compact, robust and precise (Figure 1). It has two modules, each of them comprises three cameras and one pattern projectors, which form a stereo camera viewpoints. The stich of the two images from the two modules are correlated upon the projected pattern, which achieved rapid 3D image display and the geometry accuracy is 0.5mm. The coverage is 180 degree (ear to ear), the capturing speed is 2 milliseconds.

Figure 1: Facial scanner (3dMD, USA)

Establish the reference frame

Precise volume measurements rely on locating the registered facial scan images in identical positions during image analysis. This presents a challenge as the patient's head position and sitting posture vary between appointments. To overcome this variation, a reference frame was developed to achieve uniformity in the alignment and positioning of facial scan images. The reference frame was determined by three points, namely, the two outer canthi of the eyes (A, B) and one deepest point on the midline of nasal bridge (C), as illustrated in Figure 2 (**I**). These points were selected as they provided relative stability, and facilitated reproducible identification regardless of the head position of the subject when the scanning was take place.

Using a three-dimensional analytical software (Cloud UCL, UK), the reference frame, as indicated by the red line in Figure 2 (**II**) was horizontally aligned and point C centred in the forward direction. This allowed registered facial images from scan appointments to be aligned consistently, such that the individualised ROI corresponded during successive image analysis. The subsequent volume measurements were calculated over each ROI, using identical software as for facial image positioning.

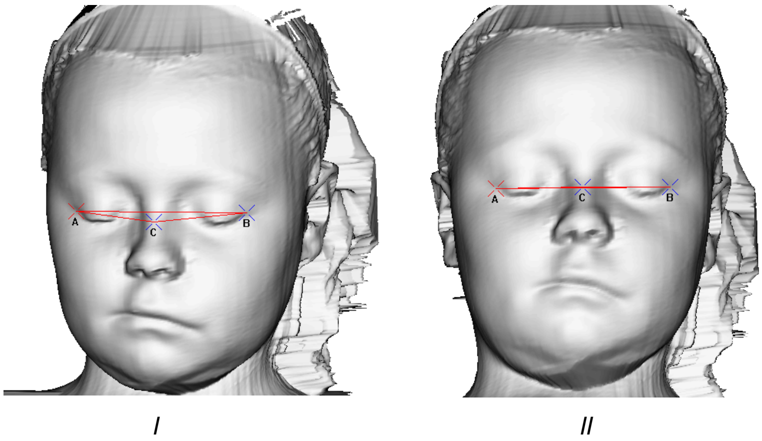

Figure 2: I & II: (I) displaying the three reproducible landmarks A&B - Outer canthi of the eye, C - deepest point of the middle of the nasal bridge; (II) demonstrating the reference frame drawn across points A, B and C (red line) horizontally aligned with point C centred in the forward direction.

Evaluate the accuracy of the reference frame

If the three vertices of the triangle ABC are:

$$\boldsymbol{A} = [x_A, y_A, z_A]^T; \quad \boldsymbol{B} = [x_B, y_B, z_B]^T; \quad \boldsymbol{C} = [x_C, y_C, z_C]^T$$

We can put all the coordinates of the three vertices ($\boldsymbol{A}$,$\boldsymbol{B}$,$\boldsymbol{C}$) into a vector:

$$\boldsymbol{v} = [x_A, y_A, z_A, x_B, y_B, z_B, x_C, y_C, z_C]^T.$$

The cross product of two edge vectors of the triangle is:

$$\boldsymbol{n}(\boldsymbol{v}) = (\boldsymbol{A} - \boldsymbol{C}) \times (\boldsymbol{B} - \boldsymbol{C})$$

$$= [-y_B z_A + y_C z_A + y_A z_B - y_C z_B - y_A z_C + y_B z_C, x_B z_A - x_C z_A - x_A z_B + x_C z_B + x_A z_C - x_B z_C, -x_B y_A + x_C y_A + x_A y_B - x_C y_B - x_A y_C + x_B y_C]^T$$

$$= [y_C(z_A - z_B) + y_B(z_C - z_A) + y_A(z_B - z_C), x_C(z_B - z_A) + x_B(z_A - z_C) + x_A(z_C - z_B), x_C(y_A - y_B) + x_B(y_C - y_A) + x_A(y_B - y_C)]^T$$

which gives the area of triangle ABC $|\boldsymbol{n}|/2$ and the normal vector $\boldsymbol{n}/|\boldsymbol{n}|$ of the triangle. Any change of $\boldsymbol{n}$ directly influence the quality of the registration of the images, and consequently results in an error in the volume measurement. Therefore change of the normal vector is a critical and fundamental error source for the volume measurement.

The vector change can be characterised by the derivative **of** $\boldsymbol{n}/|\boldsymbol{n}|$ with respect to $\boldsymbol{v}$, which is a matrix of 3×9 :

$$\frac{\partial}{\partial \boldsymbol{v}} \frac{\boldsymbol{n}}{|\boldsymbol{n}|}$$

If the bound of the change of the co-ordinates is $|\varepsilon|$, the upper bound of the change of the normal vector e can be estimated as

$$e^2 \leq [1,1,1,1,1,1,1,1,1] \cdot \left(\frac{\partial}{\partial \boldsymbol{v}} \frac{\boldsymbol{n}}{|\boldsymbol{n}|}\right)^T \cdot \frac{\partial}{\partial \boldsymbol{v}} \frac{\boldsymbol{n}}{|\boldsymbol{n}|} \cdot [1,1,1,1,1,1,1,1,1]^T \cdot \varepsilon^2$$

For example, with an average size of face, if the co-ordinates of two canthi are:

$\boldsymbol{if\ A} = [0, 0, 0]^T,\ \boldsymbol{B} = [100, 0, 0]^T,\ \boldsymbol{C} = [50, 5, -5]^T$; to take the equipment accuracy into

consideration as ε = 0.5mm

The error will be 0.0402mm [$e^2 \leq 0.1608\varepsilon^2$];

This error is purely based on the definition of the reference frame from A, B and C three points in Figure 2. This error is well acceptable for facial image analysis, as it is one tenth of the equipment accuracy.

Volumetric measurement based on the Region of Interest (ROI)

Volumetric measurements need to be calculated in a closed space, which is defined by a boundary of a Region of Interest (ROI). As shown in Figure 3, the boundary is defined in a subtracted image where the swollen took place (positive profile differences) while outside of the ROI boundary close to the 0 difference. This ROI boundary was saved in relation to registered images, therefore this ROI boundary can be recalled for later usage.

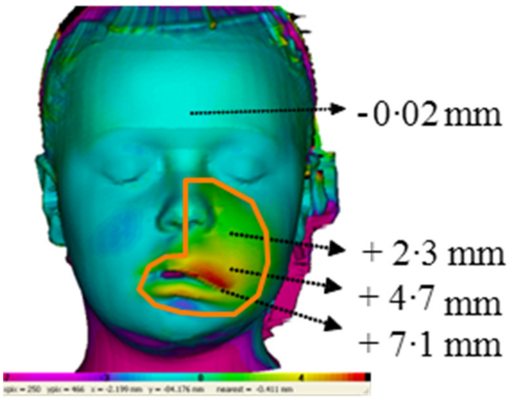

Figure 3: Colour coded images showing changes in facial profile as a result of relapse of the disease. The green, yellow and red areas are indicative of progressively increasing degrees of facial swelling whilst the purple area signifies a reduction. The closed orange lines illustrates the boundaries of the region of interest (ROI) which include areas of facial profile changes

To achieve a precise volume calculation with consecutive scan images the position and boundary of the volume both need to be precisely placed over all of the subtracted images. If the subsequent images were all registered to one image (i.e. the first scan as the baseline image), the region of interest can be aligned accurately to all of the images at the same position with the same boundary..

Results

Figure 4 illustrated the results when using three points reference frame, region of interest (ROI) definition and the satisfied the results has achieved in real cases at dental clinics.

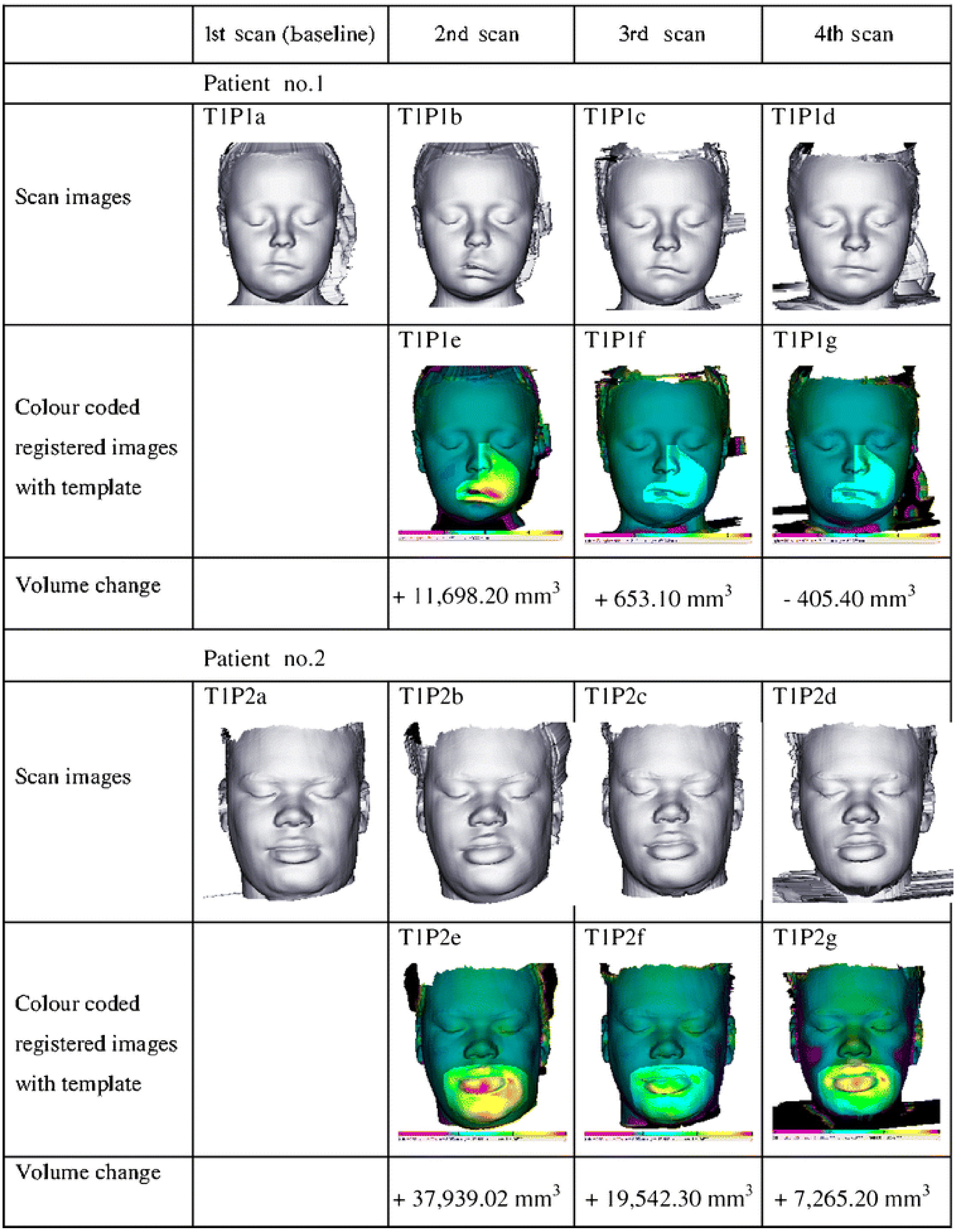

Figure 4: T1P1a/b/c/d and T1P2a/b/c/d - patient 1 and 2 facial scan images acquired at four consecutive appointments and positioned in the reference frame, respectively. T1P1e/f/g and T1P2e/f/g—second, third and fourth facial scan images registered against the baseline scan, showing the use of individualised templates for the acquisition of volume measurements. The colour coded images illustrates the profile difference and the Region of Interest (ROI) that has been accurately re-positioned to a consecutive subtracted images.

A reproducibility of test of the volume measurement, using facial features for the alignment of the sequential images, the boundary of region of interest for the calculation of the volume changes and tongue depressor for the control of the facial posture, to calculate the volume changes repeatedly for ten times and found the reproducibility of the volume measurements was less than 1%.

Discussion

With the mechanical reposition devise, it achieved up to less in 0.1mm (Roth R *at al,* 2012; Steath Product), as this value was assessed with a skeleton, which was not directly applicable to the real person or patient. Particularly if patient has discomfort symptoms such as lip swollen *etc*. By use the facial features itself, it provides a fair degree of freedom and comfort to accommodate the young and old patients who were difficult or incapable of staying still or to a specific position when facial scans were took place, consequently the reproducibility for reposition was suffered, resulting further jeopardise to the volume measurement at ROI.

The comparison of patient facial scan images acquired at different appointments is dependent on achieving a reproducible reposition. To minimise variations, previous studies have utilised the same operator, head positioning protocols and the superimposition of scans using bony (Benn *et al*, 2003, Benn *et al*, 2009) landmarks. Such methodology has addressed the shortcomings of rigidity of patients' positioning. Although these methods are useful for obtaining the profile differences, with the volume measurement, one further step have to be taken to guarantee all the consecutive scanning images were at a unique position for the boundary template of ROI to be applied throughout the multiple subtracted images, this study has demonstrated a usage of three featured points used to provide a reliably identification.

Through the mathematical model, a further discussion can be considered, to select any alternative three points and how to justify a better choice. It is indicated earlier as such, when the third point C was selected at the mid-nasal bridge, the possible error of such choice is 0.0402mm as reported in the results, however if the third point C was selected at tip of the nose, the error would be 0.000075mm. The mathematical equation reveals that the bigger the area that the triangle ABC covers, the smaller the reposition error would be.

Volume measurement is sensitive to slight changes in the position, size and boundaries from which they are acquired. To mitigate these effects on successive image analysis, a customised template illustrating the size and boundaries of facial profile changes in patients was adopted; an example of this is shown in Figure 4. This ensured a consistent tissue area and position was selected prior to performing volume measurements on successive facial images in each patient.

This approach provides an objective method for clinical intervention and routine assessment of treatment efficacy without resorting to the traditional approaches utilised in several case reports (Dupuy A *et al*, 1999, Kauzman A *et al*, 2006).

In conclusion, the technique reported in this paper offers a patient friendly, quick, robust, economical and objective approach for routine assessment of disease activity and treatment efficacy treatment. Most importantly, the technique can facilitate intervention contributing to improved treatment.

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