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Applications of photogrammetry to orthodontics

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Abstract

An investigation was conducted into the potential of utilizing standardized photogrammetry techniques to evaluate facial soft tissue morphology. A head holding device was used to provide a standardized reference system and the accuracy of repositioning for a second photographic recording was evaluated. Three dimensional co-ordinates of points on the facial surface were derived by analytical photogrammetry procedures from stereo photographs acquired via a pair of stereometric cameras. These points were manipulated via computer programs to provide frontal and horizontal face contour plots. Quantitative volume measurements determined from the skin surface to a constructed datum plane provided assessment of facial asymmetry across a constructed reproducible frontal midline, the perpendicular bisector of the interpupillary line. Photogrammetry was found to be a versatile, non-contact and precise three-dimensional recording method, with potential application to basic research and to the clinical management of orthodontic and oral surgery patients.

Key Words: Photogrammetry, stereometry, soft tissue morphology, facial asymmetry.

INTRODUCTION

Principles of Photogrammetry

Photogrammetry may be described in simple terms as the acquisition of data from photographs. Generally, stereo photography is employed to provide three-dimensional data derived from a 'stereo-pair' of photographs. Whilst the predominant application of photogrammetry is in the preparation of contoured topographic maps from aerial photographs, modifications of the technique are being applied to an increasing range of 'non-topographic' fields, including body measurements (Bjorn, et al. 1954, Newton, 1980).

Simultaneous stereo photography is obtained by using a pair of 'stereometric cameras' with parallel axes and supported on a rigid bar. The pair of stereo photographs is used to reconstruct in a photogrammetric plotting machine, the optical geometry which existed at the instant of photography. From this 'stereomodel', measurements can be made to provide data describing the model in three dimensions, and this may be visualized graphically in the form of a scale plot of contours, and profiles.

Where numerical data is required, a stereo-comparator may be used to measure discrete points on each stereo photograph from which object co-ordinates may be calculated. This approach provides maximum flexibility and accuracy. The coordinates are suitable for mathematical manipulation by computer to define specific parameters, including for example surface areas and volumes.

Photogrammetry is a non-invasive technique, eliminating distortion of the subject by contact. It provides a permanent record which may be stored in a relatively small space and may be remeasured at any time. It is an extremely versatile technique and by suitable choice of equipment virtually any desired accuracy may be achieved.

Photogrammetry in Medical/Dental Science

The applications of photogrammetry to medical fields is mainly related to the measurement of the shape and size of body parts and to changes in the form of these parts with time. 'Biostereometrics' Studies range from the analysis of very rapid eye movement to very slow growth change (Newton, 1980). The applications of medical photogrammetry, including definition and scope have been documented in some recent publications (Kerron & Karara, 1974., Coblentz & Herron, 1978., Karara, 1979).

Photogrammetry in Studies of Facial Dimensions

Many reports have documented the use of photogrammetry in studies of facial contours. These include measurements of post-operative swellings (Bjorn et al, 1954), facial changes associated with loss of teeth (Haga et al, 1964) and pre- and post-surgical changes in soft tissues after surgery have been studied in single photographs (Wictorin et al, 1971) and in stereo photographs (Berkowitz & Cuzzi, 1977).

Beard and Burke (1967) have utilized a simplified camera/plotter system to visualize facial soft tissue changes and outlined specific changes during adolescence (Burke & Beard, 1979) including the general tendencies for the serial growth changes in the lips (Burke, 1980).

MATERIALS AND METHODS

(i) Positioning Method and Stereo Photography

This study was undertaken as an initial basic exploration of the feasibility of using a head stabilizing device in facial photogrammetry and the utilization of the technique for measuring facial right-left asymmetries was studied. Seven (7) subjects were studied on two occasions. During the first visit, the head was accurately located using a cephalostat aided by four individual locating and moulding mechanisms developed from a two-stage impression technique. The four areas in contact with the cephalostat were the bridge of the nose, the external auditory meati and the occipital area (Figure 1). On the second visit, the stereo photographic records were re-taken using the cephalostat positioning devices, and five points inscribed on the cephalostat. These points were used as control points from which three dimensional facial measurements were extrapolated.

The Carl Zeiss SMK40 stereometric cameras used were permanently mounted 40 cm. apart on a rigid base and close-range lens attachments provided a camera-object distance of approximately one metre. Photography was imaged onto 90 x 120 mm. glass plate negatives. (Figure 2).

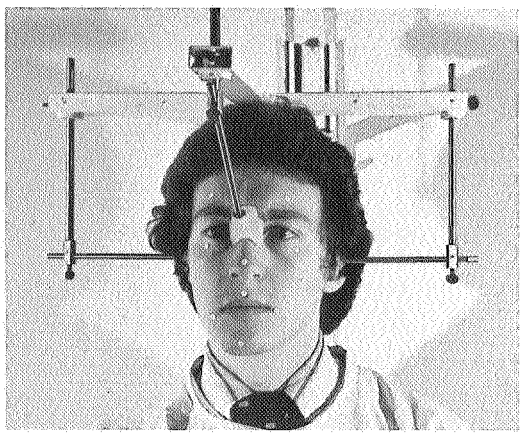

Figure 1 Subject with head firmly held in cephalostat by four point contact.

Figure 2 Photographic session set-up showing stereometric cameras and subject in cephalostat.

(ii) Data Manipulation

Each stereopair of negatives was measured one pair at a time on the Zeiss Jena Stecometer by an experienced Technician and the measurements were computer processed to provide three-dimensional object co-ordinates relative to the control points on the cephalostat.

In the initial pilot study, a digital model of one face was formed, consisting of some 600 observed points which required two hours of Stecometer observations (Figure 3). For subsequent stereo photographic pairs, the number of facial points measured was reduced by limiting observations to the specific areas of the face under investigation. Strings of points were recorded a few millimetres apart on the outline of the lips; the observed centre-line of the face and the observed horizontal profiles through the upper and lower lips and chin area.

The SOLVOL (Solution of Volumes) suite of

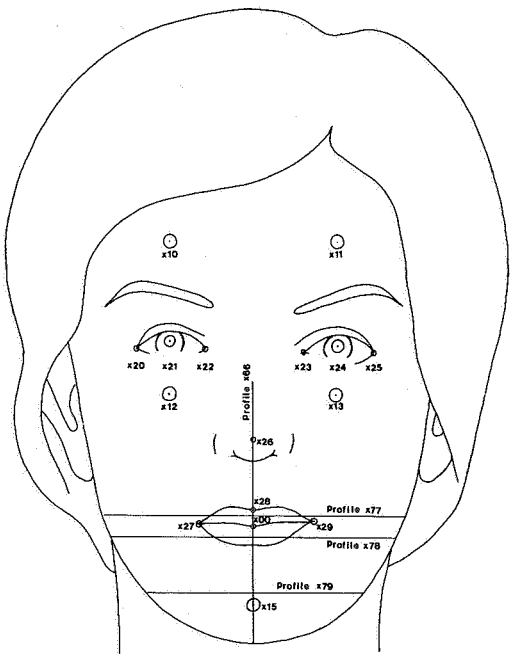

Figure 3 Shows the number coding used for facial points and profiles.

computer programs developed in the Department of Surveying was used to manipulate the data to provide contours and profile plots as well as volumetric measurements from the random data points. The points are linked to form a triangular net with subsequent volume calculations and interpolations for contour and profile plots based on this network of triangles.

Procedures for defining each of the specified parameters were:

- Contours were created by interpolating specified contour height levels for each line and then joining these to create a contour line at the indicated level above the datum base.

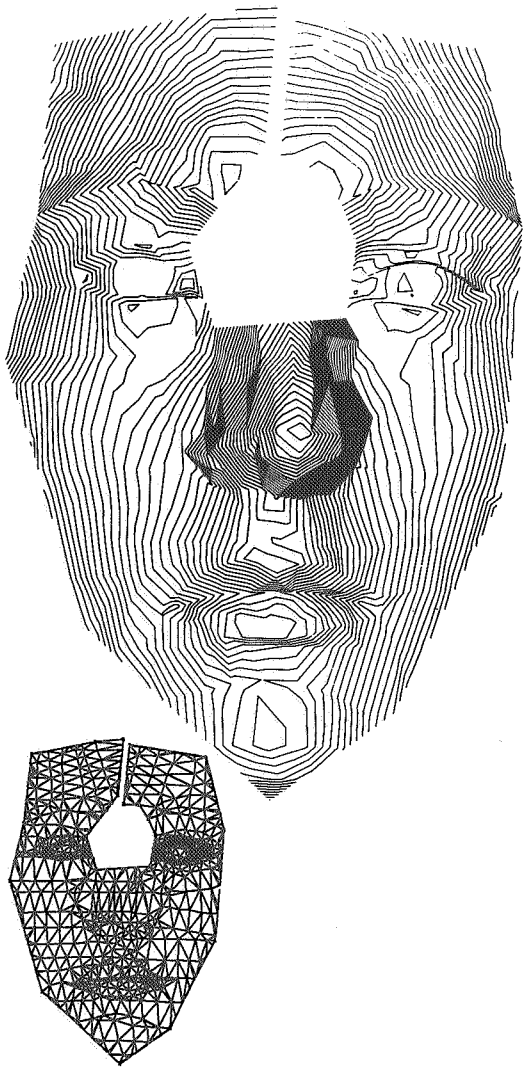

Figure 4 Computer generated contour plot of the whole face at a contour interval of one millimetre.

- Profile plots were computer generated by creating a boundary string to define a specific area and interpolating a profile plot in any direction.
- The determination of volume was achieved by projecting each triangle inside a given boundary string, through to a datum level. The volume was then calculated as the sum of each triangle within the specified area.

It is possible to accurately define and relocate the position of the profiles or areas by locating them relative to easily reproducible natural facial points. To compare the left against the right facial side using horizontal profiles and volume calculations, a midline was constructed as a perpendicular bisector of the interpupillary line. This was done using a pen and ruler on the computer plots for the visual results and by computer program manipulation for the quantitative result.

RESULTS AND DISCUSSION

(i) Limitations of single camera photography

For many years, conventional clinical photography has been used to provide comparative two-dimensional body and facial measurements. Data thus derived is subject to errors due to perspective distortion, necessitating a long focal length camera and a camera to subject distance of two metres or more. Another difficulty inevitably encountered is that of achieving a standardized pose for the subject.

The application of photogrammetric techniques utilizing close-range stereo photographs enables the determination of precise three-dimensional co-ordinates while the effects of posing errors can be significantly reduced by the use of natural body features as control points in an analytical solution.

(ii) Precision of results

The photogrammetric equipment and procedures used in this study are capable of generating three dimensional co-ordinates with a theoretical precision of less than 0.2 mm. Repeated observations to the control points on the cephalostat and selected natural facial features confirmed the precision achieved in previous projects viz. $\pm$ 0.15 mm. for well defined target points and $\pm$ 0.25 mm. for points on the facial surface.

The errors in relocation of the head of the same subject to an identical position within the cephalostat produced an average of 0.8 mm. between relocations of the head for the seven subjects included in the study. This is similar in magnitude to results obtained by Newton (1974).

(iii) Display and analysis of data

Three methods were devised to illustrate soft tissue morphology, each being derived from the photogrammetrically determined three dimensional data points.

1. A contour plot of the face (Figure 4). When comparing the right contour lines against those on the left a fairly symmetrical chin, lip and cheek area is observed. The middle third on the other hand is less so and it appears markedly asymmetrical as the nose is seen to be displaced on the subject's left side. The area around the bridge of the nose does not show the true contours as this was covered by the stabilizing impression.

NB: The insert is of the same face but shows the triangle formation between approximately 600 recorded points. This is a useful adjunct to clinical orthodontics and oral surgery as it provides a ready assessment of the face by highlighting the surface morphology. The superimposition of two contour plots representing facial recording at different times provides a useful display of change in morphology due to corrective treatment or natural growth.

2. Horizontal profiles through the lips (Figure 5). The left profile (broken line) registered at the midline has been superimposed over the right profile (continuous line). By direct measurement the exact amount of asymmetry in the anterior-posterior plane can be found. Superimposed profiles in the horizontal or vertical direction allow accurate measurements of soft tissue differences from which information for surgical corrective procedures and assessment of post-operative success can be measured directly. The constructed midline is also a useful tool when analyzing right-left facial asymmetrics.

3. Volumes calculated from selected areas (Figure 6). The volumes may be calculated from the facial surface to datum plane, within two selected areas on either side of the constructed midline. Selected information from the computer output is seen below the facial diagrams. The volume difference indicates an asymmetry is present. As this volumetric asymmetry for various subject may be determined over differing surface areas, a direct comparison is only possible by using a linear quantity obtained by dividing the volume difference by the area on one side of the midline. This quantity, called the Asymmetry Correction Factor is thus the hypothetical measurement in millimetres which one side of the face must be moved forward or backward relative to the datum plane in order to obtain a symmetrical face. The volume of selected areas of any shape or size, in any

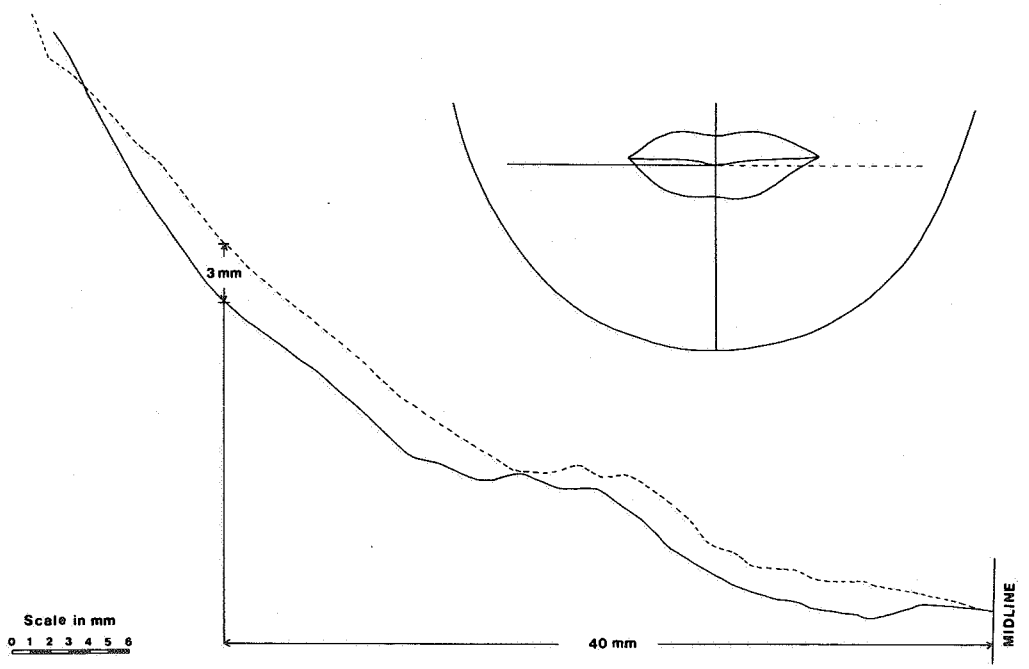

Figure 5 A horizontal profile perpendicular to the midline at a predetermined position.

number of subjects or of the same subject over a period of time can be compared with relative ease.

The use of artificial or marked points on the face at two different points in time is unrealistic as they cannot remain permanently on the face. It was found, however, that the difference in accuracy between the use of artificial and natural facial points was insignificant and thus the latter can be used to simplify data acquisition. The datum base can be extrapolated from the face thereby eliminating unnecessary repositioning error and the need for the elaborate impression techniques. The cephalostat is still necessary to standardize the head posture and provide a convenient location for the photographic control points.

As the method described is versatile and provides reliable quantitative data, it is well suited to research. With large sample groups, data could be obtained on trends in the degrees of asymmetry and in what part or to which side of the face they occur. Correlations between asymmetries and malocclusion, such as unilateral crossbites or other factors such as right or left handedness could be studied. Orthodontic and oral surgical treatment effects to the soft tissues and their long term stability can also be evaluated. This technique is currently being used to measure the effects of certain drugs on facial swelling resulting from surgical removal of the third molars.

CONCLUSION

This study provided an excellent introduction to analytical photogrammetry as a recording technique and has resulted in the development of practical procedures of potential use in orthodontics.

It was found that the difference in accuracy between the use of artificial and natural facial control points was not significant and thus the latter can be utilized to simplify the clinical photography. The use of natural feature control points in an analytical solution enables the datum base for comparative measurements to be referenced to facial features thereby eliminating unnecessary repositioning error and the need for the elaborate impression technique. The cephalostat is still necessary to standardize the head posture and provides a convenient location for the external photogrammetric control points.

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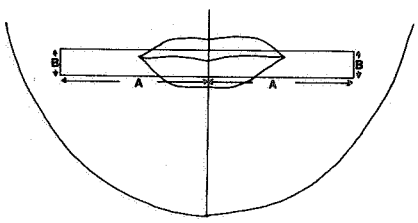

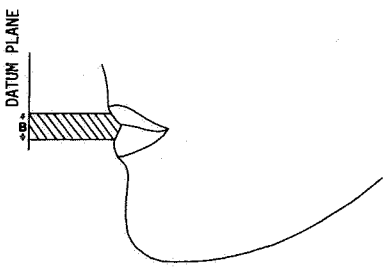

RIGHT SIDE		LEFT SIDE	
NO. OF DATA POINTS	92	NO. OF DATA POINTS	78
NO. OF TRIANGLES	101	NO. OF TRIANGLES	83
HORIZONTAL AREA	280mm^2	HORIZONTAL AREA	280mm^2
VOLUME TO DATUM	7007mm^3	VOLUME TO DATUM	7754mm^3

VOLUME DIFFERENCE BETWEEN RIGHT AND LEFT AREAS IS 746mm^3

ASYMMETRY CORRECTION FACTOR IS

$$\frac{\text{VOLUME DIFFERENCE}}{\text{AREA ON ONE SIDE OF MIDLINE}} = 3\text{mm}$$

Figure 6 The facial diagrams indicate two equal rectangular areas of length A and width B in which volumes were calculated.

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