CLOSE RANGE PHOTOGRAMMETRY APPLIED TO RESEARCH IN ORTHODONTICS

By O.W. CHEFFINS & W.A.S. CLARK
Fairey Surveys Limited

Published in The Photogrammetric Record
Vol. VI No 33 – April 1969

CLOSE-RANGE PHOTOGRAMMETRY APPLIED TO RESEARCH IN ORTHODONTICS

By O. W. CHEFFINS and W. A. S. CLARK
Fairey Surveys Limited

Abstract

Research work is being undertaken by the Department of Orthodontics at Addenbrooke's Hospital, Cambridge, which involves studying the growth of children's faces in three dimensions. In evaluating the morphology of soft tissues, the advantages offered by photogrammetry have been recognised and this paper describes how the technique has been put into practice at the hospital where a stereometric instrument, equally suitable for use as a camera or as a projection plotter, has been constructed.

INTRODUCTION

ALTHOUGH the term "orthodontics" is self-explanatory, this branch of dentistry is much less known in the United Kingdom than in the U.S.A., where the straightening of children's teeth is more widely practised. A full complement of teeth can only be straightened effectively if there is enough bone to accommodate them within the jaws. The growth of the jaws, and hence the growth of the face, is therefore of prime interest to the orthodontist. The main practical methods of studying growth of the face are by direct measurement of the surface of the soft tissues with specially designed calipers and by the measurement of bony growth on radiographs of the face and skull which are recorded in the standardised pose (Broadbent, 1931). Both of these methods have their disadvantages; soft tissues are difficult to measure by touch with consistency whilst radiographs, being projected images of bones growing in three dimensions, superimposed one on the other, often do not produce an outline which can be interpreted with certainty.

A method advocated by Angle (1907) was to relate the growth of teeth to a plaster model of the face. This is a procedure which only the most exceptional of children will suffer on more than one occasion. It appeared, therefore, that here was a field in medicine, such as those described by Miskin (1956), where photogrammetry could offer a number of advantages. The face could be measured without any contact; the actual photography could be taken with the help of an electronic flash, thereby retaining a correct pose with the patient relaxed; the exercise would not be especially arduous from a child's point of view and it would only take a few minutes to do; the records would be comparatively inexpensive and easy to file; the marking of certain features on the patient, at the time of photography, which were likely to be of particular interest in the future, would ensure that they could be examined without necessarily having to make a photogrammetric plot. It was clear that stereo-photogrammetric methods should be investigated.

PRELIMINARY TESTS IN STEREO-PHOTOGRAPHY

Initially, some experiments into the practicability of taking stereoscopic photographs were carried out at Addenbrooke's Hospital (Beard, 1967). Using a single, non-metric camera positioned successively at each end of a base plate, stereoscopic photographs of a live subject were taken. There was no intention to try to use this material for plotting, and certainly the subject could not possibly hold a motionless expression between exposures, the slightest muscular twitch being enough to impair the value of the stereoscopic view. However, these tests proved that the area of interest to the orthodontist, namely the frontal portion of the full face, could be covered by a single stereoscopic pair.

At this stage, too, it was important to devise a reliable datum within the camera's field of view to which patients could be re-oriented again and again as further photography became necessary for recording growth. A convenient and medically acceptable reference system in the human skull is the anthropological plane known as the "Frankfurt horizontal", which is defined by the plane passing through the superior rims of the two auditory meati (upper edges of the ear apertures) and the inferior margin of the left orbit (lower edge of left eye socket), as illustrated in Fig. 1. These features can easily be found by touch. The control datum decided upon comprised a rigid sheet of thick metal, 0·4 m square, with a portion cut out which was large enough to accept the patient's head. Two cylindrical, plastic rods were arranged, one at each side of this head space, so that their axes were both in line and at the same time in the plane of the datum surface; when a patient was positioned inside

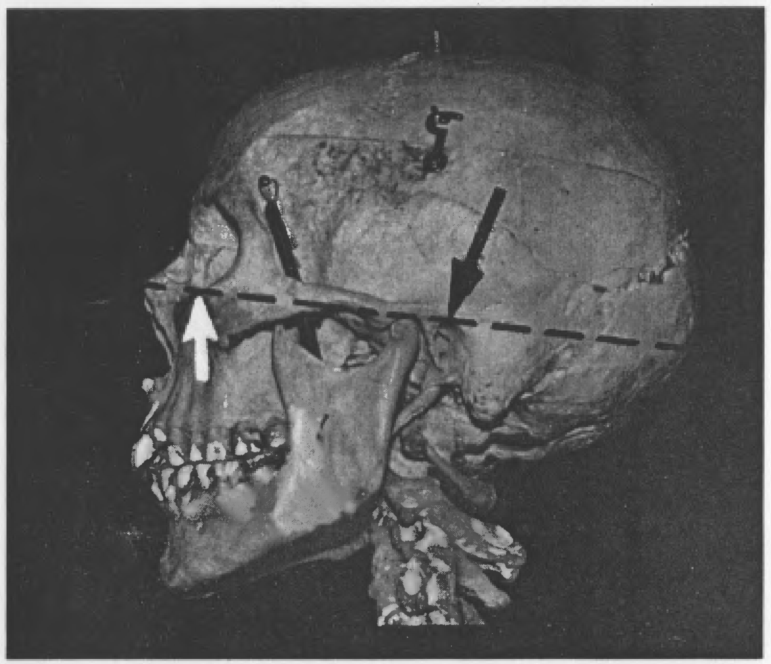

FIG. 1. Lateral view of human skull. The pecked line shows the location of the Frankfurt horizontal which passes through the lower rim of the eye socket (arrowed white) and the upper edge of the ear aperture (arrowed black).

the frame, the two rods could be carefully pushed into the ears and lodged against the meati. The position of the third datum point on the patient, the lower rim of his left eye socket, could be located by touch and a small grease-paint mark put on his skin at the vital spot. The patient's head could then be rotated on the meatal axis until, with the aid of certain calibration markers, the spot under the eye corresponded with a plane normal to the datum surface.

The late Dr. E. A. Miskin, of University College London, gave the pioneers at Addenbrooke's Hospital the benefit of his counsel. This applied especially to the photogrammetric aspects of the stereo-photographic system, such as the wise provision on the datum plate of a number of accurately measured columns of varying heights within the field of view of the camera which would provide a photogrammetric check on any departure from linearity in the *Z* range of measurement. Known distances for scaling purposes were also introduced in the planimetric dimensions (Fig. 2(a)).

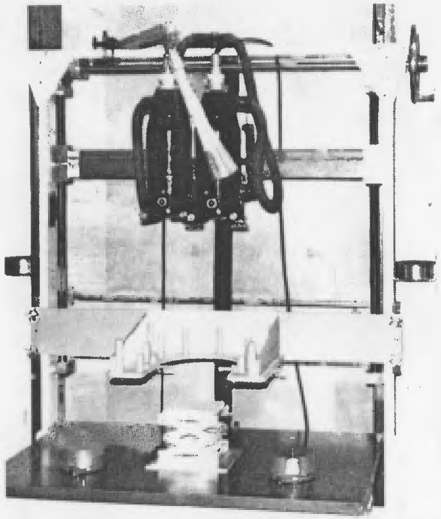

FIG. 2(a). Stereometric instrument at Addenbrooke's Hospital showing original datum frame, scale control columns, head lift and spot-light projector for maintaining correct pose when taking photographs.

DEVELOPMENT OF STEREOMETRIC UNIT AND ACCURACY TRIALS

It was known that there were several short-base stereometric cameras available commercially, but they were expensive. Also, it had been found that even with modifications they were not entirely suitable for clinical work (Beard, 1967). In addition a comparator or suitable plotting device would have to be provided for use in conjunction with these cameras, involving still further expenditure. The idea was then conceived of a pair of multiplex projectors which could be adapted for use as cameras, whilst retaining their original function as a projection plotter (Beard and Burke, 1967). Thus, by taking photographs and re-projecting the negatives through the same optical system, an almost perfect photogrammetric solution could be obtained (Fig. 2(b)). After the untimely death of Dr. Miskin in 1966, a private company (Fairey Surveys Limited) was consulted with the aim of developing such

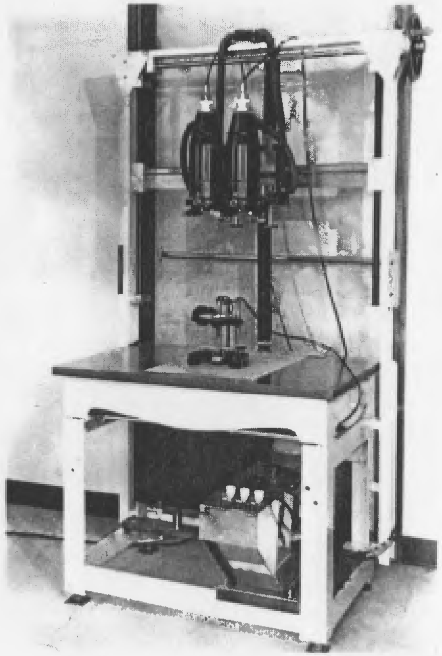

FIG. 2(b). The instrument with datum frame removed ready for use as a conventional plotter.

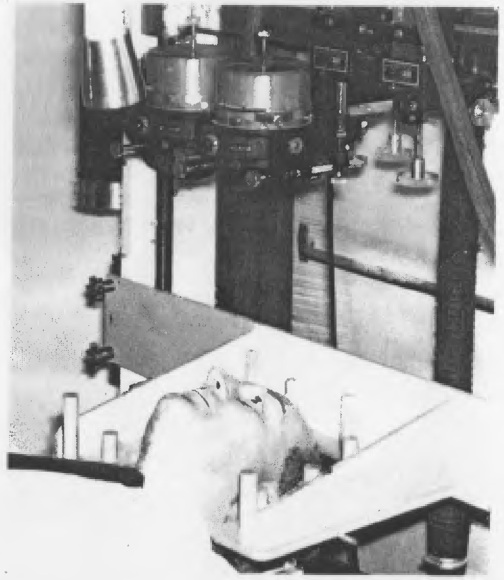

FIG. 3. Stereometric unit with plateholders in position.

an instrument for close-range work and a method of measuring the resultant stereograms.

Before the work of adapting multiplex projectors for stereo-photography was begun, some experimental photography was carried out by posing a subject (properly orientated as shown in Fig. 3) under the projectors of a standard multiplex instrument. These were loaded with unexposed photographic plates in darkroom conditions and then the subject was illuminated to make the required exposure. The negatives were subsequently re-oriented in the multiplex projectors in order to make a photogrammetric plot at a scale of 1 : 1, with contours plotted at a vertical interval (V.I.) of 5 mm. The same subject had his face moulded in gypsum, from which a positive cast was made. The reverse side of the cast was finished as a plane. This cast was then positioned under the multiplex "projectors" which again were used as cameras to achieve photography of the cast. (Beard, 1967). Another photogrammetric plot was made from the stereogram of the plaster cast, this time with a contour V.I. of 2 mm. The volume of the plaster cast was then computed in a number of different ways, as follows:

(1) Immersion in water and measuring the displacement.
(2) Reading cross-sections from the contoured plot, and calculating the volume by an electronic computer program using the trapezoidal rule and average end-area method.
(3) Measuring contour areas from the plot using a planimeter, and then calculating the volume in two ways using each of the following formulae:

(a) $V = \frac{1}{3}h[A_1 + (A_1\,A_2)^{\frac{1}{2}} + 2A_2 + \ldots + 2A_{n-1} + (A_{n-1}\,A_n)^{\frac{1}{2}} + A_n]$,

(b) $V = h(\frac{1}{2}A_1 + A_2 + A_3 + \ldots + A_{n-1} + \frac{1}{2}A_n)$,

where

V = volume,

h = contour V.I.,

A_1 = area enclosed by highest contour,

A_2 to A_{n-1} = areas enclosed by intermediate contours,

A_n = area enclosed by lowest contour.

Formula 3(a) treats the volume as if it were made up of a series of conical frustra superimposed by a cone, whilst formula 3(b) is the average end-area method applied to contours instead of cross-sections. Since the shape of the face is basically convex, formula 3(b) is more reliable, volumes calculated using formula 3(a) tending to be too small. (A way of illustrating this is to use each formula in turn to calculate the volume of a hemisphere of 50 mm radius which is contoured at 5 mm V.I., and then to compare each of the results with the true volume computed from the formula $V = \frac{2}{3}\pi r^3$. It will be seen that formula 3(a) gives a volumetric error of 2·9 per cent against an error of 1·1 per cent when formula 3(b) is used.)

The volume of the plaster cast was found to agree between methods 1, 2 and 3(b) to an accuracy of 1·4 per cent. It was decided to accept method 3(b) for determining volumes since this was the simplest to apply and gave accurate results.

Construction and Use of the Stereometric Camera

The results of these preliminary trials confirmed that a pair of Williamson SP3 wide angle multiplex projectors would form a suitable nucleus for a dual purpose

stereometric unit, and the engineers of Addenbrooke's Hospital instrument workshops were therefore commissioned to design and construct such a device, which is illustrated in Fig. 2. It resembles a twin projector plotter and is based on a rigid steel table the surface of which has been machined to an accuracy of $\pm 25\,\mu$m. The bar supporting the projectors can be easily raised and lowered by a single handwheel which has been provided at the right hand side of the instrument. This facility is necessary when going from the photographing position (where the patient's face is some 200 mm from the table top) to the plotting mode (where the projected image of the face has to be within the range of the tracing table). Each projector has been provided with a light-tight plateholder which is the same weight as the condenser

FIG. 4. Right hand view from a stereo-pair taken with the Addenbrooke's instrument showing the secondary frame in position above the datum which carries the meatal rods. Ultra-violet illumination of the subject has revealed in the skin melanin-impregnated areas which are normally invisible, resulting in a heavily freckled appearance which makes an excellent image for photogrammetric analysis.

unit with which it can be interchanged before photographs are taken. The control reference used in the initial experiments was not ideal from the photogrammetric aspect because it only extended over half the model area, thereby leaving some parts of the format completely blank. This, combined with extremely large Z ranges between datum and subject made the relative orientation of the models unduly difficult. Therefore, parallel to the datum plate carrying the meatal rods and at a distance of exactly 80 mm above it, a secondary datum plane has been introduced. This can be hinged back for access to the meatal rods while the patient is being posed before photography, but when in place the new surface provides, as well as calibrated marks for planimetric scaling, a series of image points at all critical parts of the standard overlap. These marks are at a Z value near to the median contour within the area of interest and this facilitates both the relative and absolute orientation of the stereograms. The meatal rods are still visible on the model, as shown in Fig. 4, although the Z control pillars are removed when standardised equipment is subsequently to be used for plotting.

Photography is carried out with the patient lying in a supine attitude with his head resting on a small lazy-tongs lifting device placed on the plotting table under the "projectors". The head can then be raised and lowered until it is at the right level for introducing the meatal control rods into the ears. A spot is made on the patient's cheek at the lower edge of the orbit and the images of two conventional glass grids are shone onto his face from the levelled projectors which are positioned with as small a B_X setting as possible. By rotating the patient's head about the meatal axis and utilising the B_Y and kappa movements of the projectors, the Frankfurt horizontal can be adjusted to coincide approximately with the vertical epipolar plane of the instrument by making the images of the central, horizontal grid lines fall on the meatal rods and the orbital spot at the same time. As soon as this pose is achieved, a sharp light spot, from a torch fixed in a kinematic mounting, is projected onto the orbital mark. The patient is now free to relax whilst the condensers and grids are replaced by plateholders carrying unexposed plates (Fig. 3). The correct pose is then restored simply by rotating the head on the meatal axis until the light spot again shines on the orbital mark. An electronic flash is used to illuminate the subject, and the resultant ultra-violet emission, by revealing melanin-impregnated patches in the patient's skin which are normally invisible, gives the negatives the correct overall textural appearance which is so necessary for reliable photogrammetric analysis (Fig. 4). A suggestion to put ultra-violet filters permanently in front of the multiplex objectives, with a view to allowing a high ambient level of illumination in the studio, was rejected since this would have interfered with the fixed geometry of the optics on which the accuracy of the system depended.

Photogrammetric Plotting

At present, there is not a trained photogrammetric operator on the staff at Addenbrooke's Hospital, so that the instrument has not yet been used extensively for plotting, although its functions as a plotter have been tested and found to be satisfactory.

Over sixty patients had been photographed by December 1968 and contoured plots made from the stereograms by the company at the aerial survey laboratories. This has meant using another set of multiplex equipment for the work, but in each situation the projectors are levelled and the same base components are introduced. The inner orientation is done by setting the original glass negatives in the projectors and centring the principal point spot onto the appropriate black spot on the stage plates. Only small adjustments are necessary for carrying out relative orientation, although familiar procedures are adopted to make sure that all Y-parallaxes are eliminated. The model is scaled to life size by referring to images of scribed marks on the secondary datum surface whose planimetric disposition is accurately known. Absolute orientation for height is done in two stages, firstly by adjusting common ϕ so that there is no longitudinal slope on the datum surface, and secondly by a common ω rotation to bring the orbital mark on the subject's face directly above the images of the meatal rods. An index setting of $Z = 0$ is established at the lower datum surface and the model is then contoured. Generally, a vertical interval of 2 mm is used although this is sometimes decreased to 1 mm in areas of particular interest. Spot heights are recorded at salient places in much the same way as on a topographical map. All points marked on the subject before photography are also plotted, together with the outlines of the basic features, as shown in Fig. 5. These features not only enhance the drawing but help to confirm the identity of each patient, especially when future plots are made and used for comparison.

One problem which needs attention is that of eliminating posing errors. An inspection of second and third plots made from repeated photography of certain subjects indicates that the posing attitude is not always the same. Slight rotations about the meatal axis are reflected in variations of the relative altitudes of chin and forehead. Ways of solving this problem are currently being investigated.

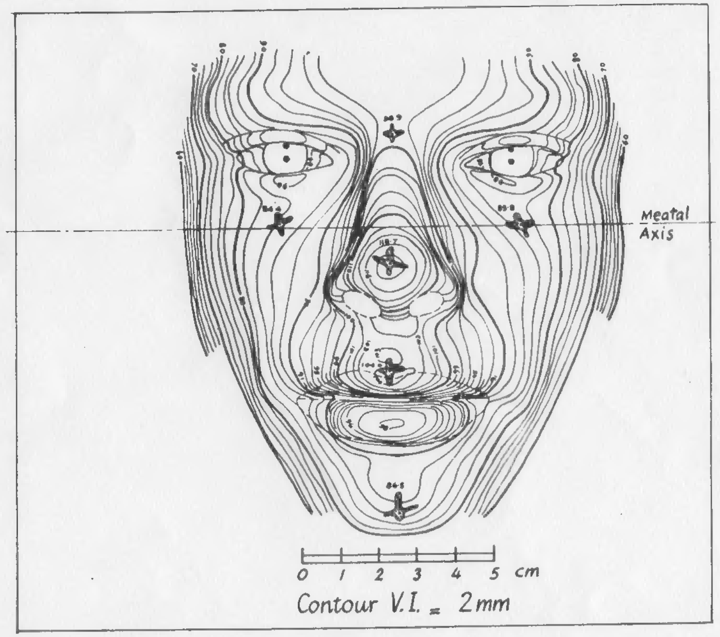

FIG. 5. Half-size reproduction of contoured plot made from photography shown in Fig. 4.

Conclusion

The successful work that has been carried out to date on the development and use of a comparatively simple, accurate and compact stereometric unit at Addenbrooke's Hospital for a specific research project should stimulate interest in photogrammetric techniques from other branches of medicine. Also, in other fields of science and technology, the methods described above could be used to advantage in evaluating the complex surface characteristics of a wide range of objects, reliable measurements of which are often needed for statistical analysis.

Acknowledgements

The authors wish to thank Mr. P. H. Burke, Consultant Orthodontist, and Mr. L. F. H. Beard, Director of Medical Photography, Addenbrooke's Hospital, Cambridge, for their great help and encouragement, without which this paper would not have been written. They are also grateful to Mr. Burke and Mr. Beard for providing the orthodontic references as well as the original material for the illustrations.

References

ANGLE, E. H., 1907. *Treatment of Malocclusion of the Teeth.* 7th Edition. S. S. White Dental Manufacturing Company, Philadelphia. 628 pp.

BEARD, L. F. H., 1967. Three-dimensional contour mapping by photography. *The Photographic Journal*, 107 (10): 315–323.

BEARD, L. F. H., and BURKE, P. H., 1967. Evolution of a system of stereophotogrammetry for the study of facial morphology. *Medical and Biological Illustration*, 17 (1): 20–25.

BROADBENT, B. H., 1931. A new X-ray technique and its application to orthodontia. *Angle Orthodont.*, 1: 45–66.

MISKIN, E. A., 1956. The application of photogrammetric techniques to medical problems. *The Photogrammetric Record*, 2 (8): 92–110.