# AUTOMATIC GENERATION OF FACIAL DEM s.

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ABSTRACT.

There are a handful of methods currently employed to produce three dimensional computer models of the human face. Among these, stereophotogrammetry and laser profiling have been used extensively. Unlike other methods in use the method presented utilizes multiple stereo models of four charge-coupled device (CCD) captured images and for comparative purposes four Rollei 6006 images to cover the whole face. Using a least squares grey level stereomatcher and seedpoints automatically generated, a dense disparity map is produced by a matching process which grows out from the seed points. From camera parameters which are determined by the bundle adjustment method the disparity map is transformed to an absolute co-ordinate system of the control points within the object space. The resulting data set is used to provide surgeons with pre and post surgical management information including profiles of the face, angles and distances between strategic features.

KEYWORDS: Digital Elevation Models, automated seedpoints, area correlation matching, facial surface models.

## 1.0 INTRODUCTION.

Orthodontists and maxillo-facial and plastic surgeons require knowledge of the shape and size of the human face to estimate population norms and to evaluate changes with growth and cosmetic facial and jaw surgery. A careful metrication of the facial surface is needed to meet the above requirements (Balagh et al, 1990).

A number of methods involving a matrix of mechanical probes, laser holography, Moire fringe patterns and stereophotogrammetry have been investigated as possible ways in which three dimensional records could be made of human heads. Each method has its own merits and demerits ranging from accuracy requirements, safety factor to the subject, complexity and cost of analysis. The method employed in this paper is stereo multi-camera photogrammetry. However, for medical tasks photogrammetry is confronted with problems where the differences to be measured between the original and changed face have to be done in the absence of identical points or areas of the face. The special difficulty lies in the exact definition of a reference co-ordinate system as everything on the human face is changing or imprecisely defined. Since the photogrammetrist and surgeon have different aims, the photogrammetrist has to find what information (lengths, angles, areas, volumes, shifts, rotations, inclinations, scale changes, asymmetries etc) is needed and how accurately it has to be determined and measured. Consequently, a suitable method to visualize the results of the measurements or computations has to be developed so that the surgeon immediately sees what he needs to see as well as provide simple tools which require minimal training to enable the surgeon to make photogrammetric measurements.

## 2 EQUIPMENT SETUP, IMAGE ACQUISITION AND PROCESSING.

The system described has been installed in the Orthodontics department of Kings College Dental School and consists of four Pulnix CCD cameras and four Rollei 6006 cameras mounted on a rigid semi-circular bracket as shown in figure 1. These cameras are used to acquire images of a subject in a convergent manner at the same time in order to get complete coverage.

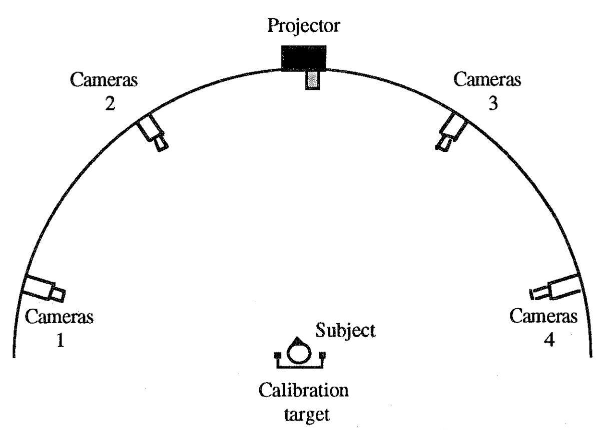


Fig. 1: Setup of cameras and projector on the rig.

To capture images, the subject is made to position his/her head within a three dimensional control target consisting of twenty-five control points distributed around its volume. Some fine scale texture in the form of either grid lines or random texture is projected onto the subjects face. Once the operator is satisfied with the position, the cameras are triggered simultaneously with the help of a switch. The four CCD cameras are connected to a Matrox IP-8 acquisition board with 2Mbytes of on board memory installed on an 80386 IBM compatible PC running at 25MHz. The board comes with software primitives for performing multi-frame acquisition. The size of each image is 512x480 pixels and a pixel quantisation of eight bits. The distribution of control points over the target is such that at least eight control points are imaged on each frame, hence providing an over determined problem when solving for the orientation parameters of the cameras in the bundle adjustment. Once the stereo imagery has been obtained, they are processed to reduce noise and correlated using a coarse-to-fine area based stereo-matcher and in the conventional manner using stereoplotting.

The production of surface models from pairs of stereo images may be subdivided into three independent stages. Firstly, a stereo-matching procedure (Otto & Chau, 1989; Muller, 1989) is used in order to identify a dense array of conjugate points. The output from the stereo-matching stage is a dense Digital Disparity Model (DDM) or a set of 2-D [x,y] correspondences over the stereo extent of the imagery. The second stage involves the calibration of the sensor and the production of a mathematical model of the sensor used to acquire the imagery, thus allowing conjugate points detected by the stereo-matcher to be transformed into 3-D [x,y,z] co-ordinates generated by the camera model onto a regular grid so that the results may be manipulated easily and comparisons can be made between different data more easily (figure 2).

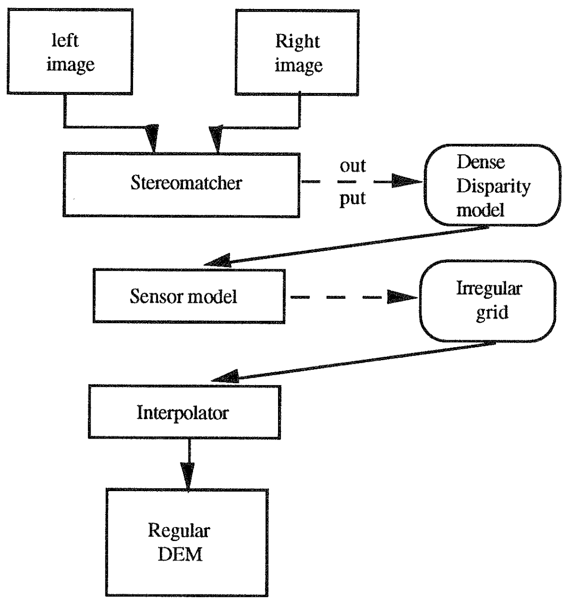


Fig. 2: Flow chart showing DEM production.

## 2.1 STEREO-MATCHING.

Earlier work on the same rig (Deacon et al, 1991) yielded absolute accuracy to within 0.5 mm (rms). This accuracy is higher than that required by either orthodontic or orthognathic surgeons. However, the problem being addressed here is not that of accuracy but of sampling density of the data. In order to increase the amount of data, the extent of the imagery successfully stereomatched needs to be greater. Area based stereo matching techniques such as the Adaptive Least Squares Correlation (ALSC) region growing methods (Gruen, 1985; Otto & Chau, 1989) requires an initial set of corresponding points (seedpoints) in the left and right images to begin stereo-matching. Feature based matching which extracts a few distinctive features (edge, line, interest etc) from the images with the aid of some operator is used. The selection principle of these interest points should fulfill five requirements. These are distinctness invariance, stability, seldomness and interpretability (Foerstner, 1986). The interest operator used is the Foerstner interest operator based on the error ellipse of the normal equation matrix N

$$N = \begin{vmatrix} \sum G^2{}_x & \sum GyGx \\ \sum GyGx & \sum G^2{}_y \end{vmatrix}$$

where Gx and Gy are the partial derivatives in X and Y respectively. The sums are calculated in a user specified window size (typically 7x7). The output of the conjugate points of the Foerstner operator are used to initiate the stereomatcher (Allison et al, 1991). These seedpoints are always determined from the highest resolution images.

A coarse-to-fine matching strategy (Zemerly et al, 1992) consisting of four image resolution levels was used. Each higher level image was reduced by a factor of two begining with an image size of 512x480 at the bottom and one of 32x30 at the top. Matching begins at the upper most level, with the co-ordinates of the seedpoints determined at level 0 having been reduced by the necessary factor. All the successful matches are then cascaded onto the lower level. The initial seedpoints are again reduced by the necessary factor for this level plus all the points inherited from the top level all used in this new level. This process continues until the lowest level of the pyramid is reached.

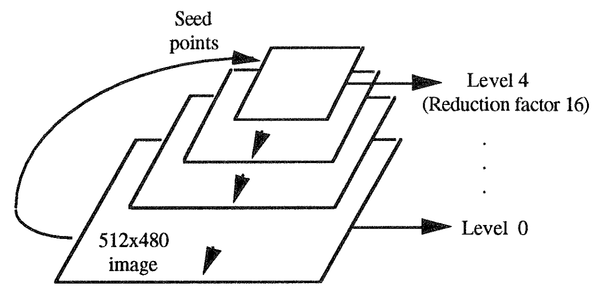


Fig. 3: Illustration of the coarse-to-fine matching.

The stereo-matcher is based on Gruen's adaptive least squares correlation algorithm, ALSC (Gruen, 1985) extended by Otto and Chau's region growing algorithm (Otto and Chau, 1989). The technique basically works as follows: Co-ordinates of initial pairs of approximately matching points in the left and right image are determined either by hand digitising on a workstation screen using a mouse, or by the use of interest operators. Each of these seed stereo-matches can be used to determine a disparity vector linking the image points. Five or six disparity values are required to allow the automatic sheet growing stereo matching algorithm developed at University College London *, to be applied to the images. Gruen's algorithm considers a patch of area around a seedpoint in the left image and finds the patch in the vicinity of the corresponding seedpoint in the right image such that the sum of the square of the differences between the grey levels in these patches is minimised. The patch is allowed to be distorted in the right image by an affine transformation ( i.e simple rotation, translation and scaling), and different illuminations are allowed for by multiplicative and additive constants. The location of the matching point in the right image is thus improved from the initial estimate provided by the seedpoint, to the pixel most closely corresponding in the right image to the seedpoint in the left. The disparity for the point is found by subtracting its co-ordinates in the right image from coordinates in the left.

Gruen (1985), has shown that the "precision" of the match can be expressed as the maximum eigenvalue of the shift parameters in the covariance matrix. The magnitude of this eigenvalue is inversely proportional to how good the match is. Consequently a maximum eigenvalue is specified, and if the best match has eigenvalue above this limit then it is considered to have failed and the point is rejected. Otto and Chau (1989) use ALSC to grow a region of matched points from the initial seedpoints and then from subsequently matched points. It takes a point in the neighbourhood of a matched point in the left image, and uses ALSC to find a matching point in the right image starting at the same disparity - thus increasing the number of matched points by one. The region continues to grow in this manner until it extends it in all directions producing a point with eigenvalue exceeding the acceptable limit.

* 3-D Image Maker won the 1990 British Computer Society award for Technical Innovation.

3. RESULTS.

A pair of stereo images were acquired using the close range vision cell at the Orthodontic Department, Kings College Dental Hospital London. These images (only with a grid projection) are shown in figure 4 and figure 5. The stereo-matcher was applied to the images in a conventional manner and in a pyramidal manner using both manually and automatically generated seedpoints. Fig 4 shows the left and right images with the seedpoints while figure 5 shows the matched areas superimposed on the pair of images. Table 1 shows the number of matched points and the time taken to stereo-match the images on an unix workstation. Figure 6 is a plot of the processing time against matched points

| Pattern Projected | Number of seedpoints | Matches | CPU time |
|---|---|---|---|
| Regular Grid | 12 | 3 671 | 410.6 s |
| Random | 34 | 4 611 | 512.6 s |

Table 1: Stereomatcher results using automatically generated seedpoints on the 512x480 images.

| Image Size | Reduction factor | Matches | Cumulative CPU time |
|---|---|---|---|
| 32 x 30 | 16 | 273 | 12.3 s |
| 64 x 60 | 8 | 1 845 | 109.0 s |
| 128 x 120 | 4 | 8 783 | 767.5 s |
| 256 x 240 | 2 | 9 676 | 1 393.3 s |
| 512 x 480 | | 10 099 | 1 664.1 s |

Table 2: Results of the coarse-to-fine matching.

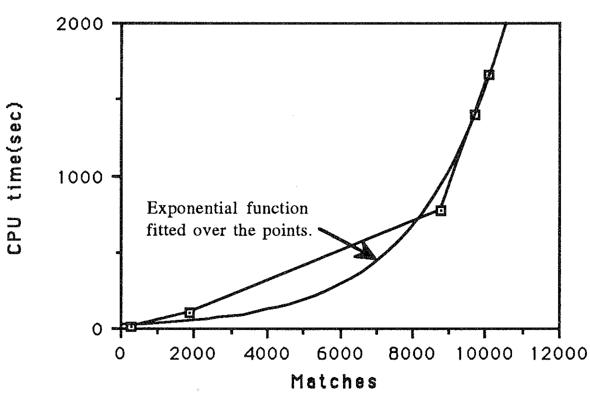


Fig 6. A plot of CPU time against matches of the coarse-to-fine matching.

A triangulated surface consisting of Delaunay triangles through the set of 3-D points is then generated. The surface which is generated consists of triangles using a subset of the stereomatched input points as vertices. Not all of the input points are used. If the difference in height between a point at position x,y and the value of z at x,y on the surface of the triangle encompassing that point is less than a tolerance value given as an option on running the triangulation program, then the point is considered unnecessary and is omitted (DeFloriani, 1989). Hence a surface is generated using the minimum amount of data needed to represent the surface to within the specified tolerance figure 8.

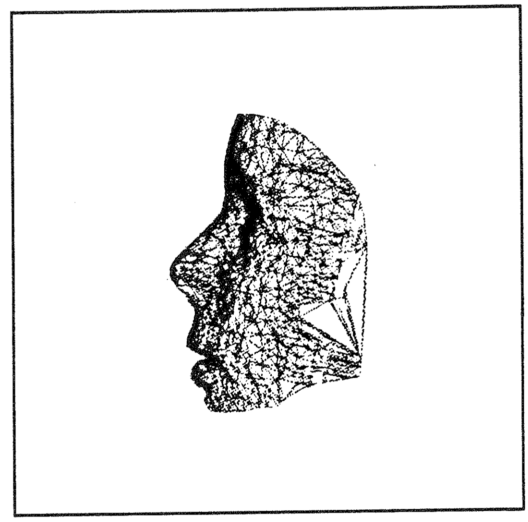

Fig 8. Example of a facial DEM generated from output of the stereo-matcher.

4. CONCLUSION.

A system has been described which can be constracted to generate automatically a large set of stereo correspondences so that a facial surface model may be produced. The measurement accuracy of this system meets the requirements for surgical planning and treatment monitoring. In facial applications, the widespread acceptance of 3-D non-invasive biostereometric systems depends on the ease with which these systems can be used. The biostereometric system advocated here uses autoseeding area correlation matching algorithm in conjunction with a pre-calibrated cell. The system is therefore well suited for use by medical personnel who are not skilled in either Photogrammetry or computing. The speed of the system could be improved in the future by using transputer elements based on T9000 ( see Zemerly et al., 1992)

5. ACKNOWLEDGEMENTS.

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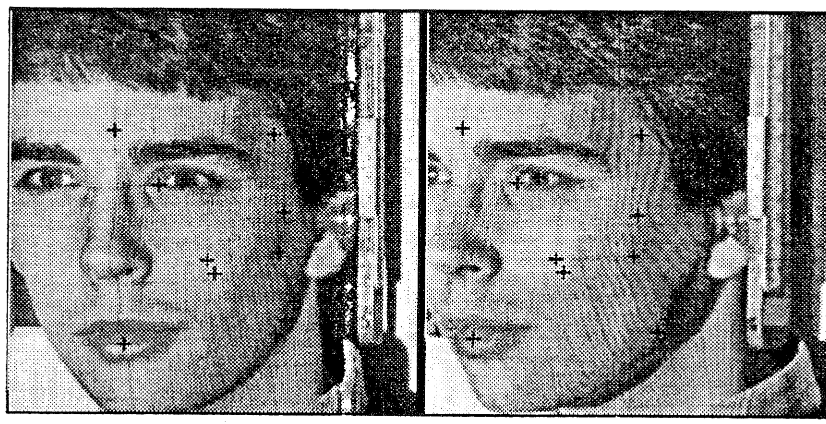

Fig 4. Automatically generated seedpoints shown as crosses on the images. Images captured by CCD cameras.

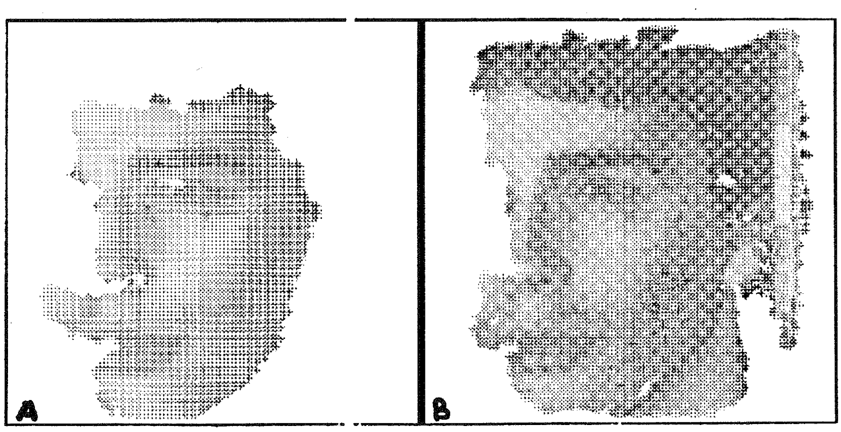


Fig 5. Two left images showing output of the stereo-matcher superimposed on the original images.a) using single level matching and b) Pyramidal matching