An Economical Approach to Measuring Anthropological Shapes by Photogrammetry

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ABSTRACT

After a comparative view at the different methods comprising the family of generalized stereophotogrammetry, this paper deals with an economical photogrammetric measuring approach initially designed to provide information for Scoliosis diagnosis. Simple equipment (photographic enlarger and digitizer) plus a rigorous bundle adjustment incorporating system calibration used in a "black box" mode, makes it suitable for use by non-photogrammetrists.

INTRODUCTION

In view of using it for the application for the pre-radiography diagnosis of spinal deformity, a generalized photogrammetric measuring system for anthropologic shapes was studied. Since the concepts could be adopted generally to any shape measurements, a comparative review of the methods within the family of generalized stereophotogrammetry is provided. These include:

- (conventional) stereophotogrammetry;
- light sectioning;
- Moire topography;
- rasterstereography;
- line-sensing.

Following these studies, a film-based system, which excludes any requirements for specialized photogrammetric instruments, has been designed for use by non-photogrammetrists in a non-photogrammetrist environment. One of the design criteria was the use of readily available system components, such as a non-metric camera, a photographic enlarger, a 2-D cartographic digitizer, and a rigorous bundle adjustment.

COMPARATIVE REVIEW OF METHODS WITHIN THE FAMILY OF GENERALIZED STEREOPHOTOGRAMMETRY

a) Stereophotogrammetry

For this project, stereophotogrammetry is defined as a process in which objects are imaged on a pair of overlapping photographs and then analyzed.

Stereographic interpretation.
Stereophotogrammetry is a singular process to transform a three-dimensional object space to a two-dimensional image space (Thompson, 1975). In conventional stereophotogrammetry, inverse-perspective transformation of at least two overlapping photographs is used to recreate three-dimensional object information from the images.

Accuracy factors.
The accuracy relies heavily on the geometric configuration and on the accuracy of image coordinates, where the geometric configuration includes the imaging system itself (interior) and the arrangement of the

imaging system (exterior). Pre-analysis could be done in the following way by assuming the normal case (El-Hakim, 1979):

$$\Sigma_{XYZ} = \sigma^2 h^2 \begin{bmatrix} nf^{-2} & 0 & f^{-1} \sum_{i=1}^{n} x_i^{-1} \\ 0 & nf^{-2} & f^{-1} \sum_{i=1}^{n} y_i^{-1} \\ f^{-1} \sum_{i=1}^{n} x_i^{-1} & f^{-1} \sum_{i=1}^{n} y_i^{-1} & \sum_{i=1}^{n} (x_i^{-2} + y_i^{-2}) \end{bmatrix}$$

(x, y) --- image coordinates referred to principal point;
f ------ principal distance;
h ------ object distance;
σ ----- image coordinate accuracy;
n ----- the number of photos on which the point appears.

Accuracy in the convergent case has been extensively studied in Faig & Moniwa (1973), Abdel-Aziz (1974), and Marzan & Karara (1976).

Advantages

- This technique has the full benefit of the excellent resolution of a lens-film system.
- Satisfactory evaluation techniques are presently available.
- With proper design, the edge problem, caused by the fact that overlapping photographs can cover only one side of a 3-D body, could be solved by a multi-station approach.
- At least two photographs are required, but more than two can be easily implemented. This provides for higher reliability as well as accuracy.
- The geometric fidelity, both in image and station configuration, together with a satisfactory mathematical model development, generally provide the best accuracy potential in today's technology.

Disadvantages

- A pattern must be generated, either by marking the object, or by projecting a pattern onto it. Vozikis et. al. (1984) suggested wearing of specially woven clothes.
- Usually an expensive photogrammetric restitution instrument is required, and a real-time process is almost impossible.
- While dynamic studies can be done using a high speed imaging system, e.g., movie camera, as applied in Van Wijk & Ziemann (1976), restrictions exist, e.g., in the digitization process of the large volume of analogue data (photo), the time resolution of the high speed process and its sychronizibility.

b) **Light-Sectioning**

Light sectioning is a technique based on the projection of light through parallel slits onto an object and the subsequent photographing of the object using a single camera whose axis is aligned at 90 degrees to the projection direction (Atkinson, 1980).

Stereographic interpretation.
This system could be viewed as one perspective projection (camera) and one parallel projection (light planes). Often the image is not formed simultaneously, but with one section at a time, in other words, one profile or contour line after the other.

Accuracy factors.
The performance of the system depends on mechanical characteristics, largely the parallelity and stability of the moving light plane (slit).

The perspective characteristics of the camera are usually neglected in the interpretation. Therefore, perspective distortion exists, but it is usually not significant (with respect to the low system accuracy).

Advantages

- It is easy to operate, easy to interpret, and free from the problem of targetization.

Disadvantages

- Concave and convex features cannot be fully covered.
- It is sensitive to body movement. Therefore, dynamic study is restricted.
- Usually, the available accuracy is lower than for stereophotogrammetry, and the output is only in analogue form.
- The edge problem remains unresolved.

c) Moire topography

The system is composed of one light source, one image recording device, and one grating plane (the shadow Moire method). In some cases, two separate pieces of grating plane are used; called "the projection method" (Frobin & Hierholzer, 1982). In this technique, contours are produced on the object as interference fringes while it is illuminated by a point - occasionally also a linear - source of light through a plane grating of equally spaced lines. The fringe pattern is produced by the interference of the grating (from the view side of the image recording device), and from its shadow (from the view side of the light source) on the object. This pattern may be recorded either monoscopically or stereoscopically.

Stereographic interpretations.
Moire topography could be physically interpreted by either two perspective projections (in the case when radiating light is used), or one perspective projection and one parallel projection (in the case when parallel light is used, e.g. in Terada & Ikeda (1978)).

Due to the fact that a grating is opaque to light, and that the interference from an equally spaced grating produces a pattern of iso-lines, the 3-Dimensional information can be condensed into one single photograph. In other words, the height information is assessed by "optical computing", and recorded on one photograph (Frobin & Hierholzer, 1982).

Accuracy factors.
The geometrical quality of a Moire photograph depends on the accuracy with which the various components of the instrument, i.e., the camera, the light source, and the screen are aligned, and the distances between them are defined. Other possible error sources are imperfections of the screen and camera distortions. The accuracy analysis of conventional Moire topographic instrumentation has been discussed in Van Wijk (1979).

Advantages

- The operation and interpretation is simple, instantaneous, and fast.
- Dynamic study could be easily done by using recording devices such as a movie - or video camera.
- It is very effecitve for the pre-radiography mass screening program. This technique is in a fully operational stage.

Disadvantages

- The edge problem remains unresolved.
- High resolution and high accuracy are not easily obtainable.

- A digital automated process is difficult due to the analogue nature of its output.

d) **Rasterstereography**

One projector and one camera compose the system. Either a linear or raster pattern can be projected.

Stereographic interpretations.

Rastersterography is similar to conventional stereophotogrammetry. Two perspective projections are used. The only difference is that one image is reversely projected from "image" space to "object" space. With this condition, only one image has to be digitized. Meanwhile, the image pattern which could be stereoscopically evaluated by this "pair" is limited in the pattern which has been projected and simultaneously photographed.

Accuracy factors.

The accuracy is also similar to that of conventional stereophotogrammetry. One point to note is, that in this case the mathematical model used has to be more general. The "camera" has totally different characteristics; which implies that each "camera" should have its own calibration parameters. The precision of the projected "image" coordinates will be generally different from the precision of the sensed image, as will the digitization accuracy along the axes.

The accuracy gained from a multi-station approach is not practical because then the merits gained by reducing the image digitization are virtually lost. Also the distribution of the stations is heavily restricted.

The multi-realization in the time domain has the potential to improve the reliability and stability of the system. Both a sophisticated mathematical model and data handling algorithm are yet to be developed.

Advantages

The great merit of this technique is its simplicity and fidelity to automated evaluation. Only one image has to be digitized. When a linear projected pattern is applied, the digitization is simplified from point digitization to line digitization. With a "well calibrated" stabilized system, the computational requirement is significantly reduced to a direct space intersection.

Because the output information is directly in digital form of the 3-D point coordinates, automated analytical evaluation is very promising.

In most applications, as in Frobin & Hierholzer (1982, 1983), a solid-state linear camera was used as the sensor. In the data analysis, the point detection (control points) and raster line extraction were automatically executed. In Frobin & Hierholzer (1985), the linear camera was replaced by a metric camera for better geometric quality and stability which would simplify the computational work; the image scanning and feature extraction procedure remained the same. These examples show, that fully automated data reduction is very impressive.

Disadvantages

As stated before, the image pattern which could be stereoscopically evaluated by a "pair" is limited in the joint set of projected and photographed patterns. Because one point projection can cover only one side of the object, there are heavy restrictions on the goemetrical configuration and selection of camera stations. Moreover, the edge problem still remains.

The mathematical model and analytical processing scheme still need further refining and investigation.

e) **Line-sensing**

Basic concepts.

This technique utilizes a "projector" and one "camera". The pattern is projected once for each line, and the "camera" senses the image one line per frame. After the projector completes all the line projections, all the sensed frames are "superimposed" (analytically rather than physically) into one frame. The resulting image is the same as that in linear rasterstereography.

Stereographic interpretations.

As mentioned above, this technique can be viewed as piecewise (line-wise) linear rasterstereography. However this step-by-step image forming will result in different characteristics from those techniques previously described.

Accuracy factors.

According to today's data processing procedures outlined in El-Hakim (1984), the accuracy is heavily affected by the stability of this system and the completeness of its calibration.

Advantages

This technique simplifies the feature extraction algorithm. One "bright" line on the black background is easily detected. This permits the parallel processing of image sensing, feature extraction and parameter determination, resulting in a "real-time" process.

The most significant application potential for this technique is in robot-vision.

Disadvantages

There are many aspects of the technique that have not been well understood. This may be so because of its recent development.

The high metric information quality relies on the sensor technique and on the analytical evaluation model.

When considering the advantages and disadvantages of the various methods, it appears that rasterstereography and line-sensing are most appealing, primarily because of their potential for digital processing.

DESIGN AND TEST OF A FILM BASED SYSTEM

Given the goal of high fidelity in the digital process, rasterstereography and line-sensing look most appealing. However, considering the present status of these techniques, a film based system was designed and tested.

During the design of the film-based system, a 2-phase approach was chosen. That is, the calibration phase and the measuring (working) phase were separated. This approach was used by Ruther (1984) when surveying whales by photogrammetric means with a non-metric camera system. Although this concept was developed rather early with a pre-calibrated stereo-metric camera, the application of the 2-phase approach to this particular system needs further investigation.

For regular maintenance re-calibration, the method applied in Armenakis (1983) could be adopted, where the control points are used only once in consecutive photographic missions.

Utilization on non-metric projector and non-metric camera.

The film-based test system utilizes a 3M overhead projector and a non-metric camera. A Wild C-12 stereo-metric camera was also used independently to provide reference data. The following arrangement was used:

	focal length (mm)	object distance (m)	photo scale
3M overhead projector	355	2-3	1:10
Olympia OM-10 (standard lens)	50	2-3	1:40
Wild C-12	64	2-3	1:40

The projected raster was scribed on a Wild A-10 plotting table with a line width 0.6 mm. Twenty-one projected points on a cylindrically-shaped tan papar were photographed and digitized on the Wild A-10 plotter. Bundle block adjustment was performed with GEBAT-V (El-Hakim, 1979), and minimum datum definition (2H, 3V). It should be noted that the size of the projected object points was around 6 x 6 mm^2.

The following results were obtained after the bundle adjustment:

photos	σ_x	σ_y	σ_z	condition
1,2,3	1.1	1.2	1.5	all I.O. fixed
1,2,3	0.9	1.0	1.8	free (xp, yp)
1,3	1.2	1.0	1.2	all I.O. fixed
6,3	2.1	4.1	3.0	free (xp, yp)
6,3	2.3	4.2	3.3	free (xp, yp) and additional parameters

photos 1,2 --- stereo-pair from Wild C-12;
photo 3 ------- pseudo photo by 3-M projector (geometric center used as principal point);
photo 6 ------- photo by OM-10.

In the table above, standard deviations in object space were obtained from the comparison with intersected coordinates from Wild C-12 measurements. Besides, 3 directly measured distances were used as another reference.

distances	direct measurement	photo (1, 2)	photos (1,3)	photos (6,3)
1	0.650	0.645	0.646	0.646
2	0.640	0.637	0.638	0.643
3	0.645	0.643	0.643	0.649

Considering the point definition, there is good agreement for all 3 combinations.

The utilization of enlarger-digitizer approach

Using a model test, the enlarger-digitizer approach was investigated using rigorous bundle adjustments with additional parameters.

The data from the enlarger-digitizer combination was prepared in 3 ways for further computation:

Set 1. By a 2-D conformal transformation, the original digitized data was transformed to approximately the same scale as the original negative (enlargement ratio = 1) with minimum control (2 points), for ease of comparison.

Set 2. By a 2-D perspective transformation with minimum control, enlarged and digitized data was transformed into the original negative measured on the Wild A-10 stereoplotter.

Set 3. Same as 2, however, redundant observations were used to perform a least-squares adjustment.

The first set shows the original behaviour of the enlarged and digitized data, while the other 2 sets are expected to show the effect of the combined lens distortion because perspective errors have been taken care of.

All data were cleaned using the data snooping method, which is implemented in the program GEBAT-V, with C = 4.1. Then, all data were analysed with both GEBAT-V and UNBASC-2 (Moniwa, 1977), with and without additional parameters.

The test data consists of a test object, which has 61 object points. The reference data is the original negative measured on the Wild A-10, used as a mono-comparator. The 4 times enlargement was done on a Durst M35 enlarger. An Altec digitizer (resolution 0.025 mm) was used to digitize the enlarged photo prints. Thus, the estimated accuracy in the original negative scale was expected to be approximately 6.5 μm.

Table 3.2. Comparative Results with Enlarger-Digitizer Data

set	add.. par	Control H	V	UNBASC2 σ_{xp}	σ_{yp} (μm)	σ_X	σ_Y (mm)	σ_Z	GEBAT V σ_{xp}	σ_{yp} (μm)	σ_X	σ_Y (mm)	σ_Z
0	no	19	21	7	7	0.1	0.1	0.4	7	7	0.1	0.1	0.4
0	yes	19	21	4	6	0.1	0.1	0.2	7	8	0.1	0.1	0.4
1	no	19	21	8	10	0.1	0.2	0.8	8	10	0.1	0.2	0.7
1	yes	19	21	7	7	0.1	0.2	0.6	8	9	0.1	0.2	0.8
2	no	19	21	8	8	0.1	0.2	0.6	8	8	0.1	0.2	0.6
2	yes	19	21	6	7	0.1	0.2	0.5	7	8	0.1	0.2	0.6
3	no	19	21	9	9	0.1	0.3	0.7	9	9	0.1	0.2	0.7
3	yes	19	21	6	6	0.1	0.2	0.8	9	9	0.1	0.2	0.7

Note: Set 0 consists of the original negatives.

CONCLUSIONS

It was found that:

1. In general, the results from the enlarged and digitized data are slightly worse than the original negative-comparator approach, but still rather close.

2. The results with additional parameters are consistently better than without. This was confirmed with further tests with different control patterns and is more significant in the contact copy-comparator approach than in the enlarger-digitizer approach.

3. Results with set 2 (perspective transformation with minimum constraints case) is consistently better than the results with set 1 (2-D conformal transformation with minimum constraints case). The difference showed the effect of perspective errors.

4. The results in height from conventional photogrammetry are significantly better than those in the other three. The reason might come from random errors, however, it is suspected that it was mainly caused by uncompensated systematic errors, such as radial distortion and film deformation during enlargement.

5. Although enlarged and digitized data were cleaned both with minimum and full control to detect gross errors prior to block adjustment, some gross errors have been detected by the data snooping in GEBAT-V. This reminds us that the gross errors can never be counted out. In the digitization with digitizer, the problem of lost origin was experienced due to paper shift.

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