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APPLICATION OF STEREO PHOTOGRAMMETRIC TECHNIQUES FOR MEASURING AFRICAN ELEPHANTS

A. J. HALL-MARTIN
Division of Research and Information
Private Bag X402
Skukuza
1350

H. RÜTHER
Department of Surveying
University of Cape Town
Rondebosch
7700

Abstract – Measurements of shoulder height and back length of African elephants were obtained by means of stereo photogrammetric techniques. A pair of Zeiss UMK 10/1318 cameras, mounted on a steel frame on the back of a vehicle, were used to photograph the elephants in the Addo Elephant National Park, Republic of South Africa. Several modifications of normal photogrammetry procedure applicable to the field situation (eg. control points) and the computation of results (eg. relative orientation) are briefly mentioned. Six elephants were immobilised after being photographed and the measurements obtained from them agreed within a range of 1 cm–10 cm with the photogrammetric measurements.

Introduction

Photogrammetry is generally known for its use in the production of topographical maps (Thompson 1966). However, this technique is now also applied in architecture, aircraft design, oceanography, archaeology and zoology (e.g. Adams 1978; Borchers 1964; Croze 1972; Scogings 1978; Thompson 1967). The basic principle is that the distance between any two points on an object can be derived from a pair of stereo photos taken from two positions separated in space, provided the points are clearly imaged in both photographs. As photographs alone are sufficient to make the required measurements, photogrammetry lends itself to situations in which direct access to the object is restricted or entirely impossible. This situation arises in the case of a moving object or an animal that does not tolerate direct physical contact.

Shoulder height of African elephants *Loxodonta africana* can be used for

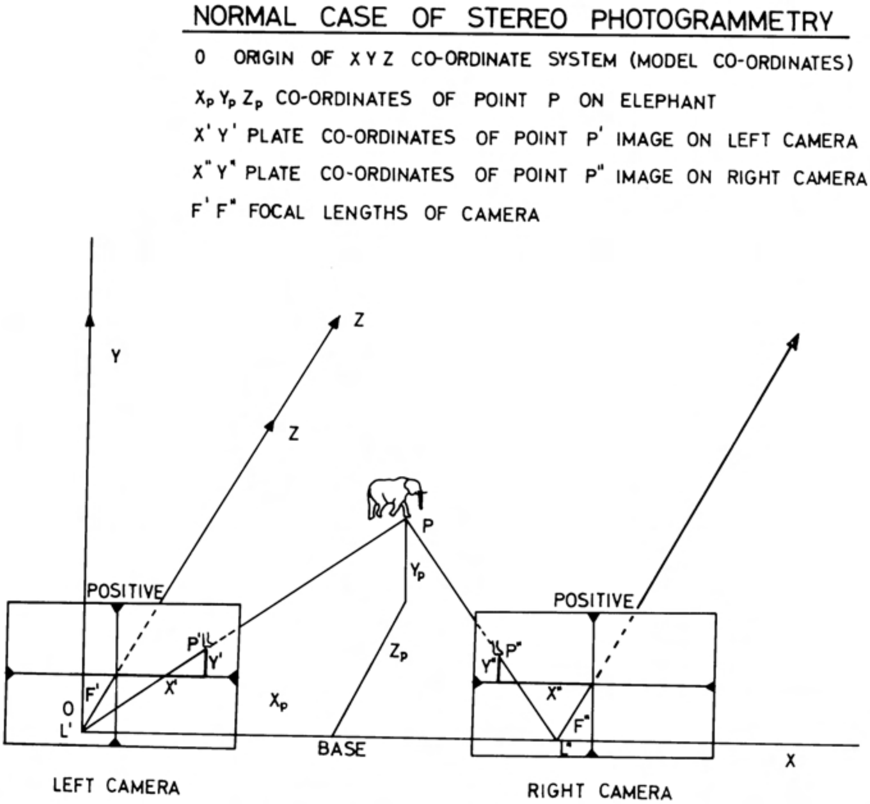


Fig. 1: Diagrammatic representation of normal case stereo photogrammetry with African elephant as subject.

To evaluate distances it is necessary to introduce a three dimensional co-ordinate system. It is convenient to designate the origin of the system as being at the projective centre of the left camera (this is approximately the external pupil of the lens system); the line from the left to the right camera or base as the X-axis (Fig. 1). The Y-axis is perpendicular to the other two axes. The X Y Z co-ordinates of any point visible on both photographs can now be derived from the position of the point's image on both photographic plates. Four fiducial marks define the plate co-ordinate system from which the point position is measured.

For the left plate the co-ordinates are X′Y′F′, for the right plate X″Y″F″. The definition of X′ (X″) and Y′ (Y″) are indicated on the diagram (Fig. 1) F′ and F″ are the focal distances of the left and right camera respectively. The measurement of X′, Y′, X″ and Y″ are carried out on either a mono-comparator, a stereo comparator or on a stereo plotter. The values for F′ and F″ are supplied by the camera manufacturer. For surveys of high precision a special camera calibration is required. If the field arrangement of the cameras is "normal case" then the space co-ordinates X, Y and Z of the object points can be derived from simple geometric relationships (Fig. 1):

$$Z = B/(X'/F' - X''/F'')$$

$$X = Z.X'/F'$$

$$Y = Z.Y'/F'$$

The distance between two points (P_i and P_j) is found from:

$$dij = [(Xj - Xi)^2 + (Yj - Yi)^2 + (Zj - Zi)^2]^{1/2}$$

Relative orientation

In many applications, as in elephant photography in the field, it is not possible to mount the cameras in the ideal normal case arrangement. The cameras are not orientated exactly parallel, they are not levelled and they cannot be set up in known space positions. The results obtained from the tilted cameras have, therefore, to undergo a mathematical treatment known as relative orientation (Thompson 1959; Schwidefsky 1959) before they can be used in the above formulae. In the relative orientation the tilts of the cameras with respect to each other are determined. Once the tilts are known it is possible to evaluate fictitious plate co-ordinates simulating the normal case, i.e. plate co-ordinates are found which would have been obtained had the cameras been free of any tilts. These new values can now be inserted in the above formulae leading to space co-ordinates of all observed points in the arbitrary co-ordinate system given by the attitude of the cameras at the moment of photography.

Absolute orientation

In conventional photogrammetry an additional calculation, the absolute orientation, (Thompson 1966; Schwidefsky 1959) is carried out. In absolute orientation the co-ordinate values undergo a three dimensional transformation into a system of known control points, which in the case of aerial photogrammetry are ground markers of known geographical or geodetic co-ordinates. In the situation given here absolute orientation is not possible, as no control points can be established on the elephant or in the surroundings. To determine the shoulder height of elephants only distances between points, i.e. relative measurements, are required, absolute point positions are not essential. It would, however, be useful to have some known control points in the field to improve the accuracy of the photogrammetric survey.

In an attempt to establish control points in a set of photographs for checking results, a series of points on a fence line near a water trough were marked and surveyed and the cameras set up in an optimum position. No elephant turned up to be photographed against the background of control markers. Under field conditions animal photography seems to exclude the use of premarks. It was therefore necessary to apply a technique of post-marking. Well defined points on bushes, trees or on the ground in the area covered by the stereo photographs were selected after photographing the elephants; the distances between these points were then accurately measured with steel surveyors tapes. The same distances were determined by the photogrammetric method and compared with the field distances. Insufficient results are available at this stage to assess the improvement and accuracy achieved by additional field measurements. This technique resembles absolute orientation and could be referred to as quasi-absolute.

Equipment

A pair of Zeiss tenoptic UMK 10/1318 high precision terrestrial stereo cameras with virtually distortion free wide angle lens systems were used for photography. Stereo cameras equipped with telephoto lenses would have been more suitable for the project but none were available. At first the cameras were set up in the conventional manner on a pair of tripods behind a fence near a waterhole. No elephants, however, came into the ideal range for the wide angle lenses (5 m–30 m) and the attempt was abandoned.

The cameras were then mounted on the back of a four wheel drive truck by means of a metal structure (Fig. 2). This consisted of a base frame

Fig. 2: A pair of UMK stereo cameras set up for simultaneous operation on a revolving mount which is secured on the back of a light truck: A– base frame; B– camera carriage frame; C– revolving hub; D– camera box; E– electrical trigger mechanism.

bolted to the truck with struts, and attached to this a camera carriage frame fixed to a revolving hub whose axis was fixed to the base frame. The carriage frame had two wooden boxes bolted to either end by means of metal plates riding on springs against which the butterfly nuts holding the camera boxes were tensioned to absorb shock. The inside of the camera box had two vertical grooves into which the camera side trunnions fitted snugly. A hole in the floor of the box accommodated the lower trunnion and the lid of the box was screwed down against the upper trunnion. The floor of the box was padded with high density rubber. The metal construction was of 16 gauge 40 mm square piping so as to provide a rigid base for the cameras. The carriage frame could be fixed in a fore and aft position by bolts during travel. An electrical shutter trigger mechanism for simultaneous operation of the cameras was fixed to the camera carriage frame. As the sensitivity of the camera mechanisms prohibited a permanent mounting of the cameras on the frame they were removed from their holders when travelling and kept in their well-cushioned cases.

Once the vehicle was in position near an elephant the equipment was set up in less than a minute (Fig. 3). This procedure is obviously disadvantageous, especially as it necessitates a relative orientation calculation for each new pair of photographs owing to the fact that an exact repetition of the cameras attitude in the frame can not be guaranteed for each new position. In the case of stereo photography of an immobile object, stereoscopy can be achieved with one camera positioned on two base points. A moving object requires simultaneous photography from two cameras and this was provided by the electrically triggered shutter operation.

Fig. 3: Stereo cameras in operation at close range to elephants in the Addo Elephant National Park.

Emulsion carrier

The UMK 10 cameras are designed to use precision ground glass plates (format 17,8 cm x 12,8 cm) as emulsion carrier. Glass plates are heavy, fragile, costly and difficult to obtain but they satisfy the requirements of high precision photogrammetry: a minimum of temperature distortion, emulsion shrinkage and unevenness. To test other materials, sheet film and roll film cut to the cameras' size were inserted into the plate holders. The roll film proved unsuitable as distortion was clearly detectable. Sheet film seems to be of sufficient accuracy and stability but further laboratory tests are considered necessary before sheet film can be accepted as the ideal emulsion carrier.

Measurements

After the plates had been exposed and processed, plate co-ordinates were measured in a comparator. A comparator allows the measurements of X–Y co-ordinates on a two dimensional object like a photographic plate, with high precision ($2\mu m - 20\mu m$). The plate co-ordinates of two points on each elephant have to be determined for shoulder height measurements. These are obviously the points where the foot meets the ground and the highest point of the scapula of the elephant (Fig. 4). Measurements can only be made when both points are clearly visible and vertically aligned, as when the elephant is standing; but not when moving due to the displacement of the relative positions of the scapulae and their height. Measurements of back length from the top of the head, midway between the dorsal points of attachment of the pinnae to a point vertically above the base of the tail (Fig. 4) were also attempted. This measurement has also

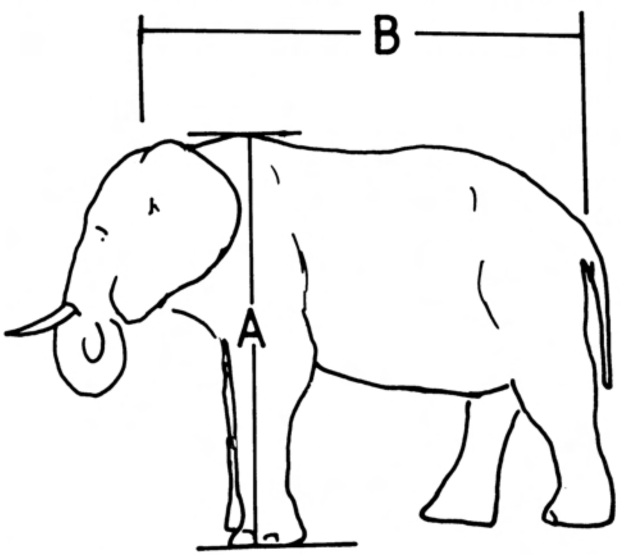
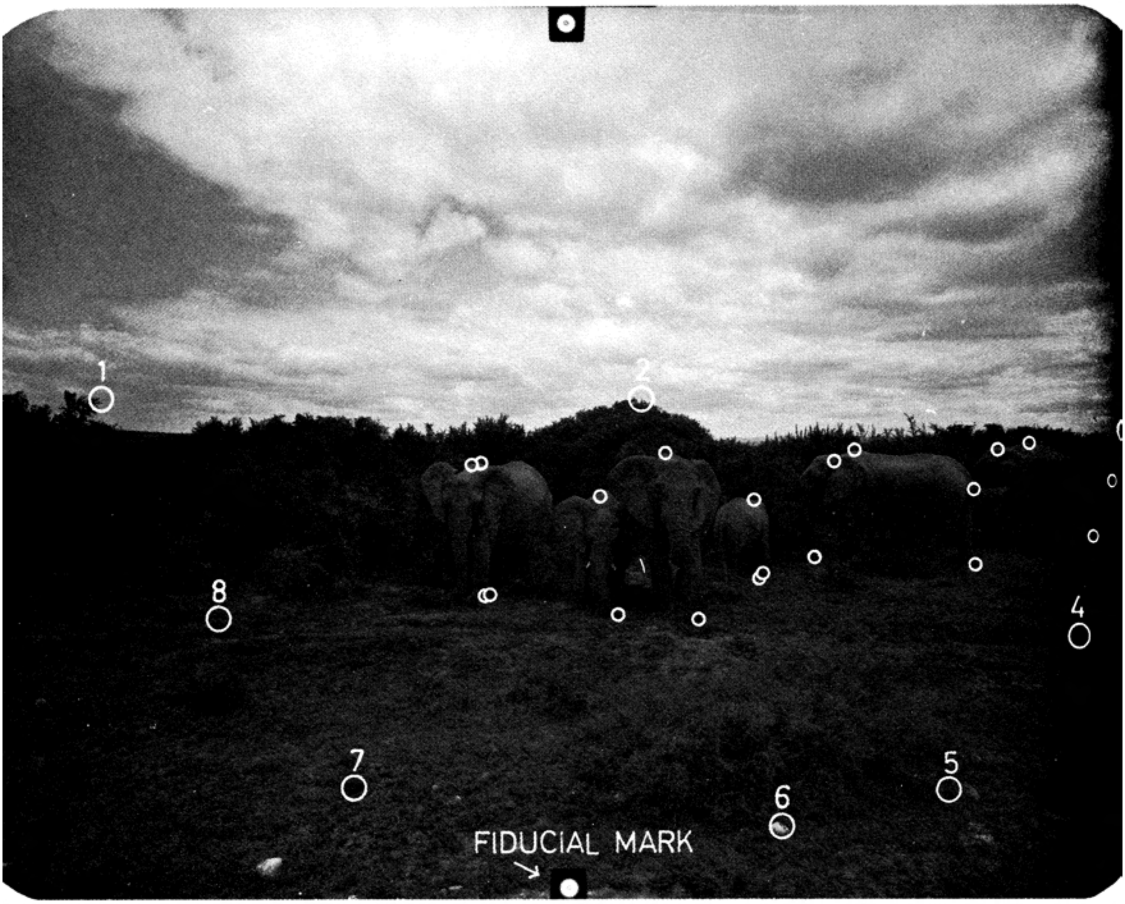


Fig. 4: Outline of adult African elephant showing points used for shoulder height measurement (A) and back length measurement (B).



been used for assessing the age structure of elephant populations (Laws 1969; Croze 1972; Leuthold 1976).

To find the relative tilts of the cameras it is necessary to measure the plate co-ordinates of a number of additional points. These points have to be well distributed over the area common to both photographs (*e.g.* points 1–8 in Figs. 5a & 5b). Any point can be chosen for this purpose as long as it is clearly identifiable on both photographs. The tip of a leaf, a kink in a branch or a small stone can serve for this purpose. The difficulty in all cases is to identify exactly the same point on both photographs. To detect gross errors in identification and to minimize inaccuracies, a considerable number of surplus points were used on all plates. The greatest difficulty encountered in the shoulder height measurements was the identification of identical points on the elephant's shoulder. This is a possible error source and it can only be overcome by repeated photography of the same animal in different positions. Few measurements of back length were obtained because, when viewed from the side, the top of the ear is usually higher than

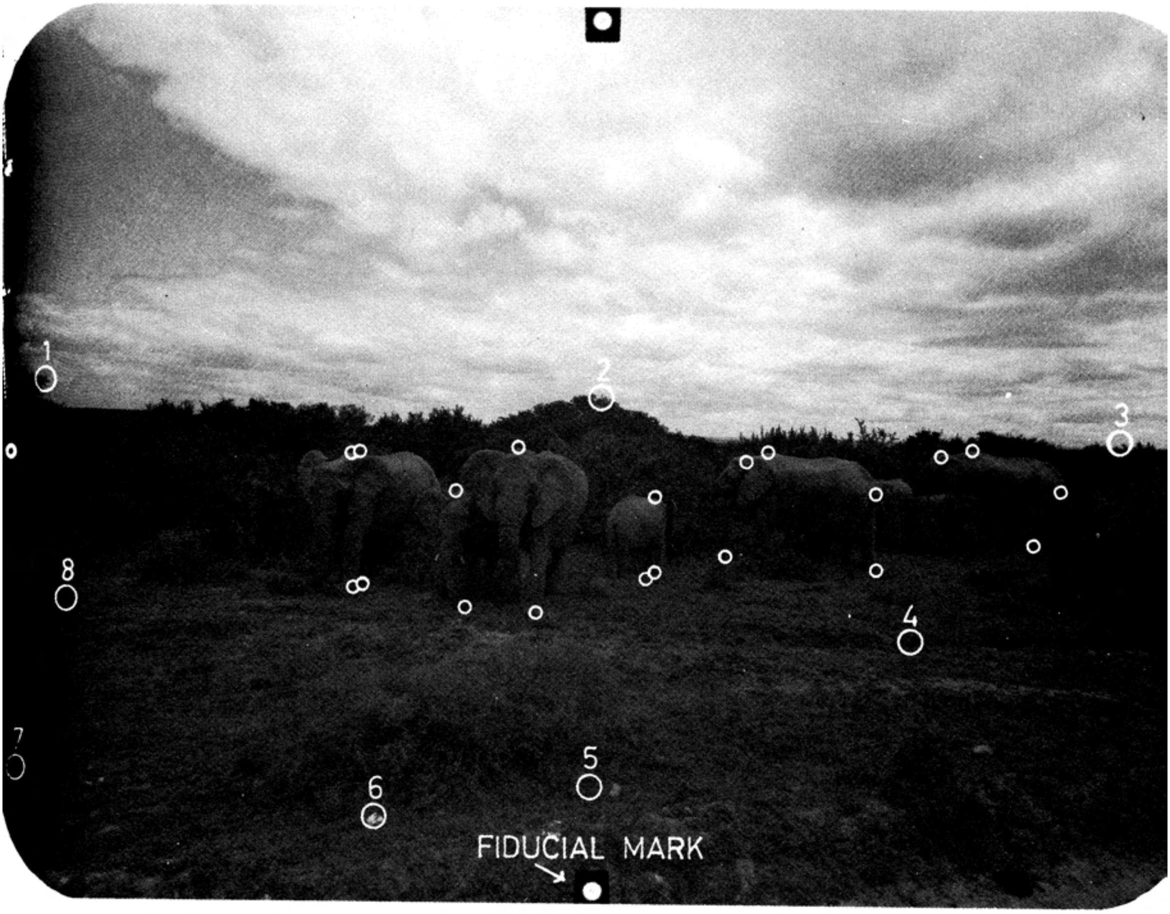


Fig. 5a and 5b: Stereo photo pair showing elephants, reference points in surroundings (numbered 1–8) and four fiducial marks of cameras.

the dorsal surface of the head; thus obscuring the centre point of the head from where the measurement is made.

It is beyond the scope of this paper to discuss the further processing of the data obtained from the co-ordinate measurements on the comparator. The mathematical process of relative orientation is intricate and especially complicated in these cases as it was difficult to find a sufficient number of well distributed points. In most stereo pairs half of the plates were covered by sky and no points could therefore be selected from the top section of the photographs. This difficulty, however, was alleviated by a modified mathematical model (Rüther 1979).

Field checking and comparisons

As all the elephants in the Addo population are individually known it was possible to select six animals, that had been repeatedly photographed, for immobilisation and measuring by manual techniques as described by Laws, Parker & Johnstone (1975). Measurements taken were shoulder height and back length. The measurements were taken 4–6 times by different people so as to assess variation due to personal bias. To minimise disturbance to the population only adult and young adult bulls were immobilized.

Results

Eighty stereo pairs were taken and in some cases as many as five pairs of the same animal could be evaluated. The shoulder height measurements of the same animals taken at different times and with the animals in different attitudes agree within a range of 5 cm–7 cm and the deviation of a single series of stereo pairs is 2 cm–4 centimetre (Table 1).

Comparisons with body measurements of six immobilized animals showed agreements within a range of 1 cm–10 cm, but the standard deviations of the photogrammetric measurements were greater than those of the field measurements (Table 1). An accurate photogrammetric back length measurement was obtained for only one of the subjects, ♂3, and was 295 cm as compared with 298 cm ± 1,7 cm (n=5) from the immobilized animal.

Table 1

Comparison of field measurements of shoulder height of immobilized African elephants and photogrammetric measurements of the same animals, Addo Elephant National Park*

Subject	Field measurements cm	± S.D.	n	Photogrammetric measurements cm	± S.D.	n
♂2	306	0,5	5	307	3,8	4
♂3	285	1,9	5	284	2,0	2
♂4	299	1,3	5	290	1,7	3
♂9	286	1,3	5	285	1,8	2
♂12	246	1,6	6	240	1,2	3
♂13	303	0,8	4	293	2,1	5

**Measurements to nearest centimetre*

Discussion

The photogrammetric results could be improved by using more suitable equipment. In the present study a Zeiss Topocart stereo plotter was used as a comparator. This instrument is, however, not strictly designed for this purpose. A more suitable comparator will shortly be available and all plates will then be remeasured.

For wider field application of the technique a more relevant improvement would be to adapt the method to use a pair of lightweight terrestrial cameras fitted with telephoto lenses. The animal would then fill a greater part of the photograph with ensuing greater accuracy and better point identification. The apparatus could then, like Douglas-Hamiltons' be readily portable, but the disadvantage of small image size would remain.

Despite the problems encountered with the technique, shoulder height measurements for 28 elephants of all ages were obtained at minimal cost and disturbance (*cf.* Fig. 3). These data have been most useful in analysing the age structure of the population (Hall-Martin *in prep.*) and when repeated after a suitable interval should give useful information on the growth of these animals.

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