TWO PHASE PHOTOGRAMMETRY WITH DISPLACED CONTROL

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ABSTRACT

If photogrammetric techniques are applied in a marine or submarine environment situations can occur where neither control points for a projective transformation treatment nor a sufficient number of object points for a relative orientation are imaged on the stereopair. The authors suggest a technique by which elements of interior and relative orientation are established in a first phase by means of a control field before each sequence of object photography. To obtain the camera pair parameters either a projective transformation model or relative orientation are employed. In a second phase, the camera pair is then swung towards the object and required object dimensions are evaluated from a second stereopair on the basis of the previously determined parameters.

The technique is tested in control fields of differing ranges and an application to the measurements of whales in Antarctica using stereophotography taken from the deck of a research vessel is reported. A pair of small format non-metric cameras mounted on a rigid bar is used to provide the photographs.

The results obtained using relative orientation and projective transformation are compared and accuracies are quoted.

INTRODUCTION

In todays environment an ever increasing number of animal species are threatened by extinction. It therefore becomes more and more important to develop efficient methods of investigating habitat, characteristics and behaviour of these animals in order to improve their chances of survival. The whale, commercially exploited by some and a highly emotional issue for others, has become a symbol of our Wildlife Crisis and extensive research is being carried out to safeguard its continued existence.

A small, but nevertheless important parameter in whale research, is the determination of the animal's length. Normally whale lengths have been either visually estimated or roughly measured using crude sight measurement devices located on research vessels.

Photography and in particular stereophotogrammetry in this measurement process would appear to be a sensible method to adopt to improve the accuracy of measurement. At the request of the Department of Sea Fisheries in Cape Town the Dept of Surveying of the University of Cape Town has cooperated in stereophotogrammetric exercises conducted on board the Japanese research ship Kyo Maru. This paper describes and demonstrates the photogrammetric solutions which were developed and applied in the Southern Oceans survey.

DEFINITION OF THE PROBLEM

Two mathematical solutions, the methods of projective transformation and of relative orientation, were independently applied to the problem of photogrammetric measurement of whales at sea. Both these techniques make specific demands on the adopted photogrammetric mode, which can not directly be satisfied when photographing an object on or just below the sea surface. The principal requirement of the so called projective transformation technique is the presence of a three dimensional control point field with known space co-ordinates in the object space. The relative orientation mode on the other hand requires known parameters of interior orientation and, to a greater extent than projective transformation, a set of clearly imaged stereo points well distributed over the object space and image format.

The establishment of a control field on a sea water surface is not feasible and only small numbers of reliable orientation points can normally be identified on the sea surface or on the whale, which itself usually fills a relatively small portion of the stereoscopic overlap. To overcome these obstacles which prevented the direct use of either method the technique of "two phase photogrammetry with displaced control" was designed and tested.

TWO PHASE PHOTOGRAMMETRY

In the first phase a control field (in our case located on board the research vessel) is stereophotographed independently of the object to be measured. For the relative orientation method it is sufficient to identify a convenient number of well defined and well distributed common image points in the stereoscopic overlap.

In the second phase photographic pairs of the object to be surveyed are exposed. For both phases it is essential that the two cameras, located at the ends of a portable base, form a rigid body unit and that neither interior nor relative orientation are disturbed between phase 1 and phase 2 photography. If this rigid body status is maintained then all images of one photographic sequence can be mathematically combined into one single fictitious pair of photographs. In this exercise a simple transformation of the whale photographs into the control photography was achieved by relating all comparator measurements of whale points and control points to the same fiducial mark systems of the left and right cameras respectively. For small format non-metric cameras such a fiducial mark system could sensibly be the four corners of the picture frame.

The combination of the two phases can be achieved through a similarity transformation with two of the four format corners as redundancies (Helmert transformation) to give a best fit shift and rotation.

Through this transformation of stereo images of the whale photography into the control photography the whale or whales have, in mathematical terms, been placed "inside" or "nearby" the control field. To achieve an optimal control - object configuration the control field should extend beyond the dimensions of the intended object and be situated at a distance from the camera base similar to the expected camera-object distance. In the case of whale photography this was usually not possible due to the limited size of the research vessel. In the event whale points were normally extrapolated beyond control point distances. The obvious weakness of the two phase photogrammetry lies in the assumption that the elements of interior and exterior orientation do not change during sequence photography and that film flatness variations do not exist. It is advisable to monitor changes in the orientation parameters by repeated photography of the control field during and at the end of photographic sequences, particularly at the beginning and end of each film spool. A rejection threshold can be decided on for the comparison of the parameters derived from the control field photography at various stages. In our case whale photography sequences can then be either rejected or evaluated on the basis of parameters derived from control photography at both ends of the sequence. The two phase photogrammetry model differs in detail for relative orientation and projective transformation and both approaches are discussed briefly in this paper.

PROJECTIVE TRANSFORMATIONS

Whilst there may be dispute regarding the adopted name of the method the method itself is particularly useful when non-metric cameras are used as a stereophotogrammetric measuring tool. Non-metric cameras are being used more and more to provide metrological information in many disciplines. To be effective photogrammetric determination of spatial coordinates through the use of non-metric cameras implies a process of what is generally referred to as self calibration. Sensibly this calibration and spatial data determination is best achieved by the use of collinearity equations in the form of bundle adjustments or projective transformations. The bundle adjustments with or without control involves a multi (normally metric) camera procedure whereas the use of projective transformations usually requires the establishment of a fixed, or portable, targetted three dimensional control system with a mimimum of six suitably sited control points; the solution being based on a two camera configuration and the calculations being performed by a variety of methods as for example the D.L.T. method (Abdel-Aziz and Karara 1971), the 11 parameter solution (Bopp & Krauss 1978) or a simplified 11 parameter solution (Adams 1981).

The elegant bundle method solution implies a good knowledge of the camera constants and is really not suited to the simple non-metric camera whereas the fully controlled projective transformation method makes the non-metric camera a useful measuring tool.

After photography the control framework pair of pictures is individually analysed to determine the b_{ij} and $\overline{b}_{ij}$ parameters of the camera configuration where the unbarred parameters refer to the left camera and the barred parameters to the right camera. The camera parameters are derived through the use of the well known projective transformation relationship between picture and space coordinates of a point

$$x = \frac{b_{11}X + b_{12}Y + b_{13}Z + b_{14}}{b_{31}X + b_{32}Y + b_{33}Z + 1}$$

$$y = \frac{b_{21}X + b_{22}Y + b_{23}Z + b_{24}}{b_{31}X + b_{32}Y + b_{33}Z + 1}$$

where x, y are rectangular coordinates of an image point referred to an arbitrary origin in the plane of the left or right picture and X, Y, Z are the space coordinates of the point.

Provided that sufficient control points coordinated in terms of the X, Y, Z space system and suitably distributed are imaged on the stereo pair of pictures and comparator (x, y) coordinates of the images are measured in the plane of the picture, solution equations in the form of equation 1 can be set up and the b transformation parameters solved for the left and right picture.

Since the transformation parameters b and $\bar{b}$ are functions of the interior, relative and quasi absolute orientation of the two camera configuration the suitably transformed plate coordinates of the second phase photography can be mathematically displaced to form fictitious images within the first phase stereoscopic pair using these control field parameters. We are only interested in a length measurement so that the real life coincidence and orientation of the axes of the orthogonal three dimensional coordinate systems is not important.

RELATIVE ORIENTATION

The relative orientation method has the advantage over the projective transformation method in that no on board control field is required. The disadvantage is that the camera calibration values need to be known. The elements of interior orientation can be determined with one of the conventional self calibration techniques in a laboratory calibration field. In the whale photography exercise the elements were derived through projective transformation calculations. For this purpose the camera objective is best taped down to a specific focus setting to ensure a constant principal distance. A setting of 25 m was chosen for the whale photography since this setting combined with a small aperture allowed in focus photography of whale and superstructure of the ship. The control field photography of the projective transformation method is replaced by photography of any section of the ships superstructure which provides a sufficient number of well distributed and clearly defined points for the evaluation of the relative orientation elements. In the "on board" case this was considered necessary as it was not possible to maintain indefinitely the relative orientation of two cameras mounted at the end of a three metre aluminium base rod (Fig 4). The elements of interior orientation on the other hand were accepted as being stable over a longer period and with careful handling of the cameras no field calibration was considered necessary.

No pre-knowledge of the relative orientation elements was therefore assumed and identical field procedures and photographic sequence as in the projective transformation technique were adopted, the only difference being that the control point co-ordinates were assumed to be unknown.

It has been shown (Rüther 1983) that in low accuracy photogrammetry the absolute orientation can be replaced by differential scaling in X/Y and Z direction. The "control field" photography of the relative orientation should therefore include a few measured distances in X/Y and Z direction of the object space. Such distances are easier to establish than a full three dimensional control field. Once the relative orientation elements have been established from the first pair of photographs of the sequence and confirmed by the last pair these parameters can be used to determine all required points on the whale photographs using the values of the "fictitious single image". Possible slight changes in the camera orientation can be accommodated by taking mean values of the parameters of the first, last and of any intermediate photograph pairs of the ships superstructure. An alternative solution is possible in a one step procedure if all image points of whales and "control photography" are used in a single simultaneous relative orientation. Fig 1 demonstrates the fictitious images technique.

The flow chart diagram (Fig 2) illustrates the procedures for both the Projective Transformation and Relative Orientation methods.

SIMULATION OF FIELD SITUATION AND TEST OF METHOD

In order to test the validity of the methods a field situation was simulated on shore. A test field similar in configuration to that on board the vessel was established and photographed using the equipment intended for use on board. Phase two of the whale photography was simulated by taking further stereoscopic pictures of the test field with the camera located some metres further away from the field thus allowing for the possibility of whales being situated beyond test field ranges. The second set was given the mathematical treatment intended

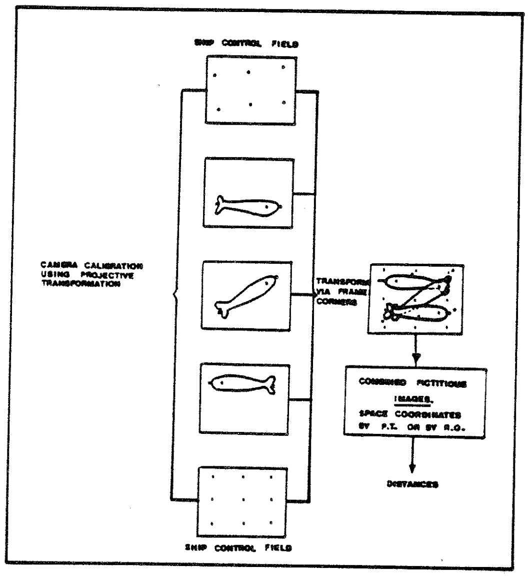

FIG 1. FICTITIOUS IMAGES TECHNIQUE

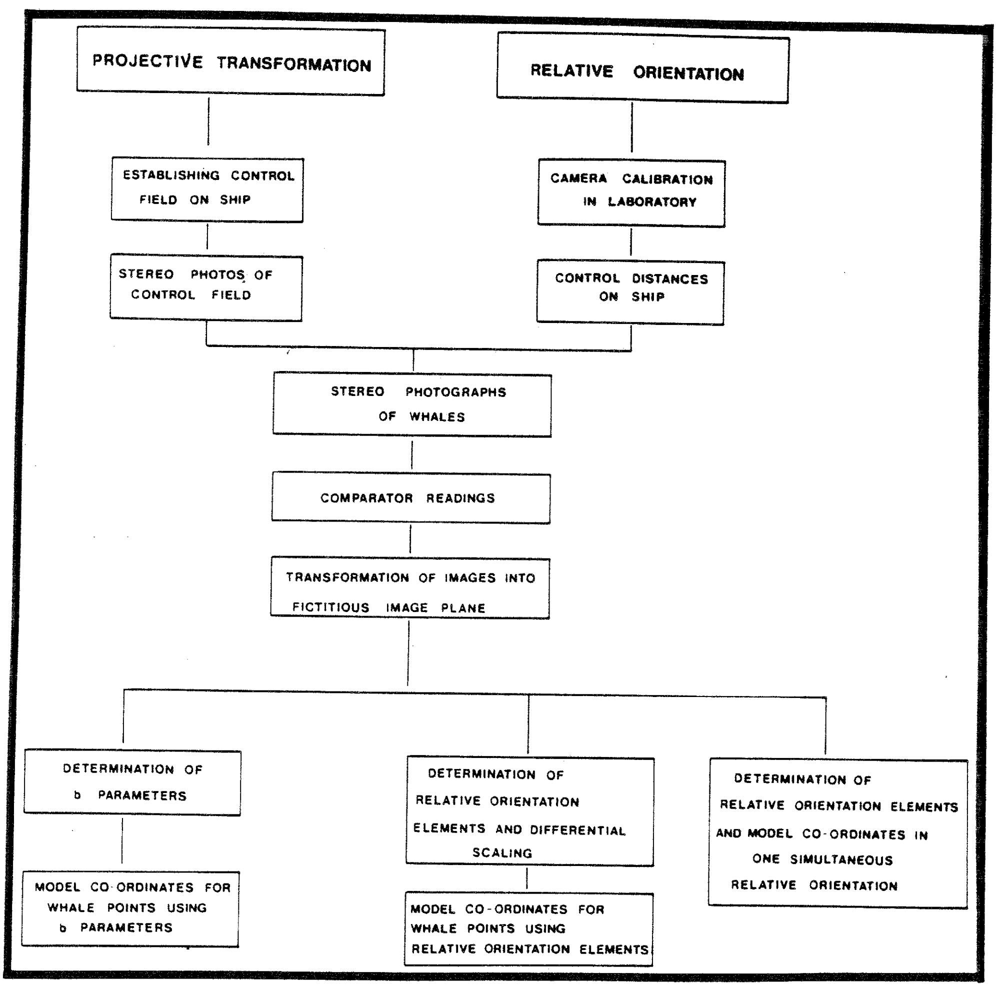

FIG 2. FLOW CHART ILLUSTRATING
TWO PHASE PHOTOGRAMMETRY PROCEDURES

for the whale photography and photogrammetrically determined distances were compared with the known values of the test field co-ordinates. The result was encouraging showing accuracies sufficient for the whale project. No significant difference in accuracy between the two approaches can be concluded from the results although values tabulated below, showing a typical example of test results, seems to favour the relative orientation method.

LINE	TRUE GROUND DISTANCE METRES	PROJECTIVE TRANSFORMATION		RELATIVE ORIENTATION	
			Diff cms		Diff cms
2 - 7	1.99	1.99	0	1.98	+ 1
2 - 8	1.71	1.70	+ 1	1.70	+ 1
2 - 11	10.00	9.96	+ 4	10.00	± 0
2 - 14	16.01	15.90	+ 11	15.96	+ 5
2 - 15	24.22	23.83	+ 39	24.15	+ 7
2 - 16	25.00	24.39	+ 61	24.80	+ 20
2 - 14	16.96	17.07	- 11	17.07	- 11
		ABS.MEAN	18.1		6.4
		RMS DIFF	28.0		9.2

ESTABLISHMENT OF SHIP CONTROL

In preparation for whale photography at sea a control field on board the research vessel comprising black crosses on a white frame varying in size between 15 and 30 cm and visible from the crows nest were painted on the superstructure of the Kyo Maru (Fig 3). The space positions of these points were determined whilst the ship was docked in Cape Town harbour. Conventional survey methods using theolodites and distance measuring apparatus had to be rejected as the vessel moved in the swell of the harbour. Two metric UMK 10/1318 cameras were employed to establish the space co-ordinates of control points using measured distances between points vertical and parallel to the camera base as a basis for deriving the space coordinates by the method of Relative Orientation (Rüther 1983).

EQUIPMENT AND FIELD PROCEDURE

The high cost, and the hostile environment of the Antarctic seas prohibited the use of metric cameras and a pair of 35 mm Ashay Pentax cameras was used instead. The cameras were mounted at the end of a 3 m aluminium tube and connected to a trigger mechanism for simultaneous photography. The cameras could be removed for transport. The aluminium base rod with the camera arrangement was suspended by means of a rope from the ships mast above the crows nest and the operator positioned in the crows nest could swing the camera towards the superstructure of the ship with its control field points and then towards whales at either side and in front of the ships bow. (Fig 4).

All photography was in colour and the plate measurements were undertaken ashore on a Steko Stereocomparator on line to a Tektronix graphic computer system.

WHALE PHOTOGRAPHY AT SEA

Whale photography in the South Atlantic was undertaken in the southern summer season of 1982/83. Inspection of the photography taken at sea shows that it is difficult to obtain photographs of whales with all points of interest (snout, blowhole, dorsal fin and tail) above the sea surface simultaneously (Fig 5). Generally the animals could be photographed with the blowhole showing above the surface together with only one or two of the oher features required for distance measurement. However measurements on two or more of these points were possible in most cases and a comparison of the results obtained using the projective transformation and relative orientation method showed good agreement. Results of a typical set of measurements are tabulated below:

LINE (See Fig 5)	DERIVED DISTANCES (METRES)	
	PROJECTIVE TRANSFORMATION (m)	RELATIVE ORIENTATION (m)
Snout - blowhole	1.07	1.10
" A	3.29	3.41
" B	7.68	7.99
" dorsal fin	9.83	10.15
" C	12.24	12.65
" tail end	13.54	13.88

NOTE: Points A, B, C are arbitrarily chosen points on the whale's back and tail.

Both the snout and tail end were slightly submerged but could be clearly identified (Fig 5). No attempt was made to correct for refraction since the sea is not placid and determination of the angles of incidence of the light rays is problematical.

If it can be accepted that the test field accuracy obtained is representative then the whale length values derived are well within the accuracy limits desired by the biologists.

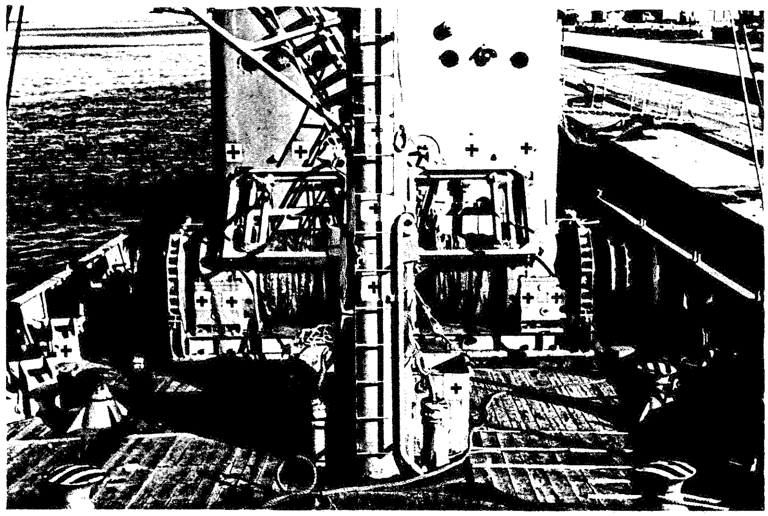

FIG 3. SHIP CONTROL FIELD

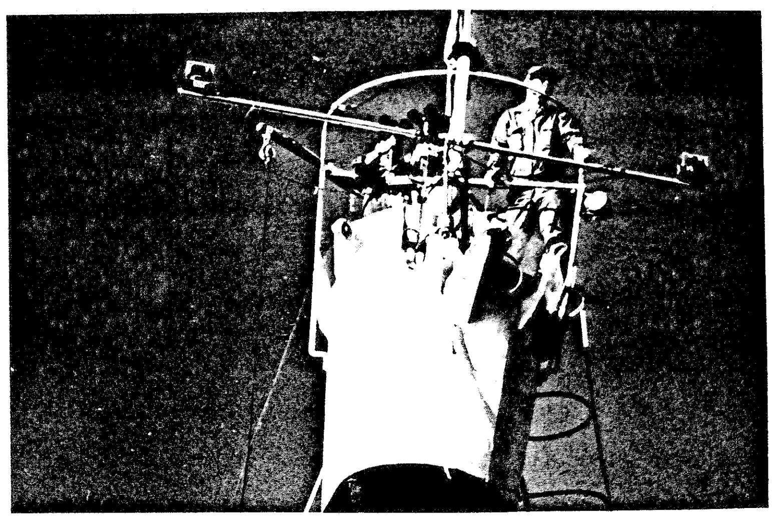

FIG 4. CAMERA CONFIGURATION AND CROWS NEST POSITION

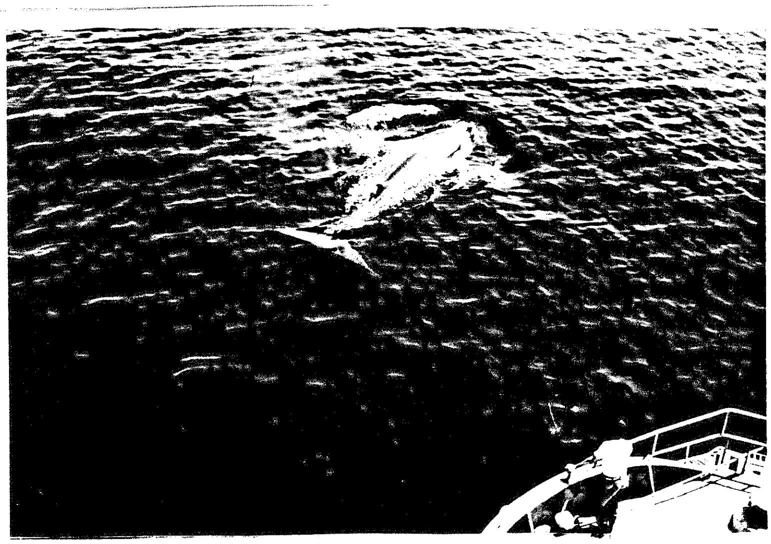

FIG 5. WHALE PHOTOGRAPHY

CONCLUSION

Using a displaced control field in combination with separate photography of control and object and subsequent combination into one fictitious photograph proved an efficient and sufficiently accurate technique for the problem in hand. The method has merit for situations with low accuracy requirements when the establishment of a control field around the object is impracticable or even impossible. Such situations occur frequently in biological applications and in cases of underwater photogrammetry as for example where stereo cameras are mounted on a submersible survey vessel.

Best accuracies can be obtained if object distances and dimensions match those of the control field or unco-ordinated point field for projective transformation and relative orientation respectively. Extrapolation from the control to the object should be avoided where possible.

As far as accuracy is concerned there is little to choose between Projective Transformation and Relative Orientation. It appears, however, that projective transformation should be applied wherever a control field with known space co-ordinates can be easily established. The relative orientation relies on constant elements of interior orientation and this assumption of unchanging camera calibration elements introduces a weakness into the otherwise reliable technique.

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