MAPPING IN SHALLOW WATER

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Introduction

Depth determinations in shallow (less than 10m depth) clear water areas are becoming increasingly important for the planning and monitoring of coastal engineering projects. In Australia, 1000 million dollars is consumed annually on such projects (Stark, 1982). Many of these projects require frequently updated detail maps of the sea or river-bed features to monitor sediment transport, scouring around bridges, siltation along breakwaters, etc.

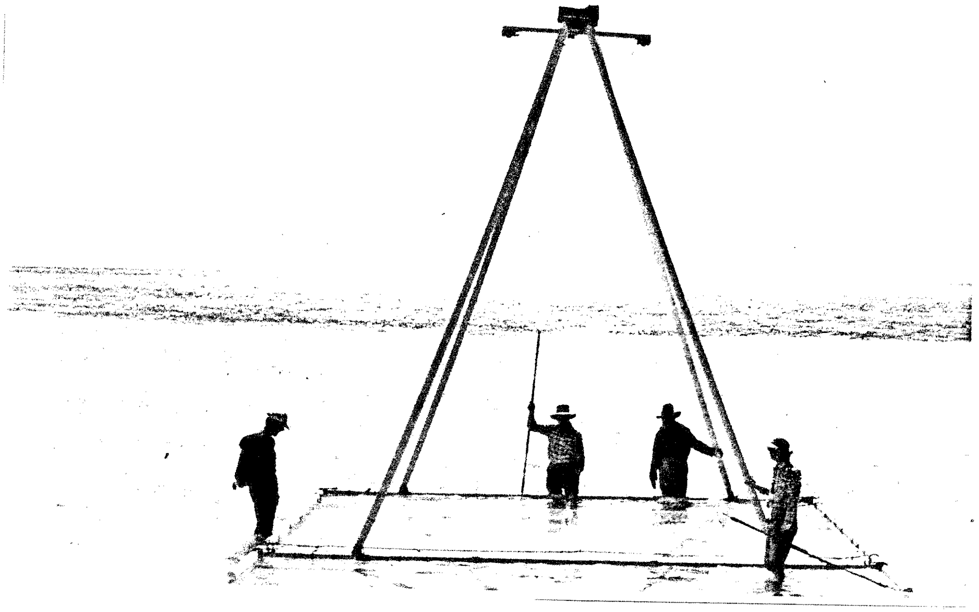
In order to answer broader ecological questions about the recruitment, growth, decay and change of marine communities, marine scientists are increasing the size of their areas. Coral ecologists, for example, are questioning the whole concept of a "balance of nature" and wish to examine life cycles over large areas of reef rather than to concentrate as they have in the past on a specific single species (Connell and Sousa, 1983).

Aerial photography has been used spasmodically to obtain details of sea-floor features e.g. Byrne and Honey (1978), Harris and Umbach (1972), Masry (1975). These results indicated an accuracy of from 5 to 10 percent of the depth in clear water areas between 5 and 10m deep, with the best accuracies obtained where the bottom had discernable rocky or reefal features, rather than sand. The errors associated with the variable refraction angles caused by ocean waves have been investigated by Okamoto (1982) and appear to be of the order of ±2 to 5 per cent of the depth, depending on the height of the aircraft. The scale of most through-water aerial photography has varied from 1:2000 to 1:10000 and, as such, has not been useful for large scale mapping.

To provide photography suitable for large scale mapping, the University of Newcastle, New South Wales, has constructed an elevated floating platform, 5.5m high, equipped with two automatic 35mm cameras (see Fryer, 1983a for construction details). The firing mechanism is radio-controlled and polycarbonate trays float on the water surface to eliminate wave ripples. This paper details the use of this floating platform to map a test area from photography at a scale of 1:180. Modifications to the software of a Qasco SD-4 analytical stereoplotter which enables two-media photography to be observed are described.

An Elevated Floating Platform

Through-water photography from a variety of elevated platforms such as model aeroplanes, balloons, helicopters and kites has been reported (Whittlesey, 1975). Many of the projects were of a reconnaissance nature over inundated archaelogical ruins or coral reefs and the ripple effect caused by breezes on the water surface was of no great concern. For accurate depth determinations, this effect cannot be tolerated. This was a primary consideration in the design and construction of the floating pyramid detailed in Fryer (1983a).



Photograph 1. The Floating Camera Platform
Note twin cameras and floating polycarbonate trays

Photograph 1 shows the floating pyramid which can be erected on land or in the water by two persons. Elasticized straps are used to join the component structural members which are watertight six metre lengths of 100mm PVC stormwater drainage pipe. Six polycarbonate trays (each 2.5m by 1.1m with sides 0.15m high and 3mm thick) lie on the water surface inside the base of the pyramid and provide a "glass bottom boat" effect. Long period waves are not entirely removed by the platform but the severe loss of image definition that is caused by wind ripple and sunlight reflection is counteracted.

Accuracy Tests

A theoretical estimate of the accuracy that could be expected for depth determinations can be obtained from a simple consideration of the geometry of stereophotography. The basic equation is represented by

$$\Delta h = \frac{\Delta p . H}{b}$$

where Δh is a difference in height related to a parallax difference Δp on two photographs taken from a height H with a photo base b. Canon AF35M cameras with a focal length of 38mm have been used on a 1.0m bar from the platform. If the camera to object distance is 7.0 metres (objects 1.5m underwater), a photo base, b, of 5.5mm can be calculated. If the precision of measuring image coordinates is ±0.01mm, the estimate of heighting accuracy is ±13mm.

The Canon AF35M camera has automatic exposure and focus, as well as motorised film wind-on. These features make the cameras ideal for remote radio-controlled operations although they do not possess an efficient film flattening device and the focal length does vary with each exposure. Recent tests carried out (Fryer, 1984), indicate film unflatness could be up to 750µm.

A series of tests to determine if this accuracy could be obtained from stereopairs were made using surveying staves held at varying angles of inclination under the water. Kodachrome ASA 64 colour slide transparencies were taken of the staves and observed monoscopically on a Kern PG2 stereoplotter that had been fitted with a tri-axis locator to provide digital recording of coordinates to 0.01mm. The analytical computation of the photo coordinates showed that a planimetric accuracy of ±1mm and a depth accuracy of ±14mm were obtained, (Fryer, 1983b). There appeared to be no significant differences in the accuracies obtained as the targets varied from 0.9m to 2.9m in depth. This test merely confirmed the precicted theoretical estimates and was not a "practical" test in regard to subjecting the equipment to ocean swell conditions and the taking of strips of overlapping pairs to form a block of photographs.

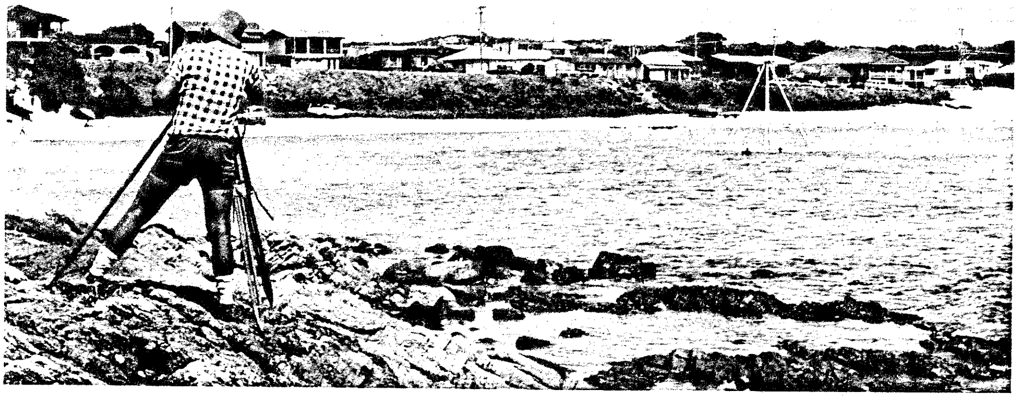
In February 1983 a more demanding test was carried out in the Port Stephens area, 200km north of Sydney, N.S.W. In an attempt to improve the accuracy of the heighting, the cameras were moved a further 0.5m apart and convergently tilted towards one another. The theoretical heighting accuracy should have been improved to ±8.5mm, but this accuracy was not achieved, probably due to the ocean wave conditions that were encountered.

Six strips, each of seven overlapping models, were photographed with the platform being manually pushed through the water in a pattern analogous to an aerial survey. An area of approximately 500m^2 at a depth between 1 and 2 metres was covered. The area was subjected to the ocean surge and small wind waves up to 200mm high. On the test day the water was not very clear as there was considerable algae in suspension.

The underwater control marks for the test area were 10mm diameter beads placed every metre along 30 metres long wires (1mm diameter). These wires were secured at each end to steel pipes whose coordinates were determined by intersection with single-second theodolites from the shore-line 40m away. Theoretically, the control beads should have been co-ordinated to within one or two millimetres. Two wires and their beads could be seen in each stereopair. One wire control line was moved at the completion of each 30 metre strip until all six strips had been photographed.

There were two main difficulties encountered by the three men tending the floating platform. The first concerned the combined effect of ocean surge and wind waves forcing air bubbles under the floating polycarbonate trays. The subsequent attempts to remove those bubbles often dislodged the trays from their fixings. This problem has been corrected by small modifications to the ropes and elasticized straps holding the trays.

The second and most time-consuming problem was in setting up and co-ordinating the control beads. The rocky nature of the bottom caused difficulties in erecting and anchoring the steel pipes at the end of each control wire. Scuba gear was not used as it would have reduced the general mobility of the crew and so, much time was spent ensuring that the control wires were not fouled. On a "normal" production job, there would not be any need for such a density of control and this would greatly simplify the operation.



Photograph 2. Positioning the camera rig, 40m offshore at Port Stephens, N.S.W. Australia

In contrast to the earlier accuracy test which had been observed monoscopically and independently computed, this larger test area was observed stereoscopically in the SD-4 analytical stereoplotter (Elfick and Fletcher, 1983). Independent models were adjusted in a block adjustment (after King, 1968), and compared with the results obtained when an absolute orientation using known underwater coordinates was performed on some stereopairs. An analytical stereoplotter was selected since detailed mapping can only be effectively carried out if the operator sees a parallax free model. Alterations to the SD-4 software removed the parallax problems of two-media photography.

Two Media Photogrammetry in an Analytical Stereoplotter

Two media photogrammetry can pose special problems when the control points are in the second medium, in this case underwater. The location of the interface surface must be determined before the amount of refraction of the light rays can be computed.

In the situation of the floating pyramid, the corners of the polycarbonate trays can be used as relative orientation points. These enable the relatively oriented model to be almost at the correct scale and they are, of course, level with the sea surface. Underwater points which are then observed are well suited to an independent model block adjustment. Subsequent to the block adjustment, it is possible, with an analytical plotter such as the Qasco SD-4, to recreate the original model after re-observing the fiducial marks and adopting the orientation parameters from the adjustment.

Many different algorithms were examined for solving the two media refraction problem. The ideal situation would have been to include a direction solution which involved a minimum of mathematical computation into the real time section of the SD-4 software. Such a solution should not significantly degrade the performance of the analytical plotter. Unfortunately all direct solutions involve the solution of fourth-order equations and are therefore very time-consuming. An iterative solution was the realistic compromise, as the solution would have to be performed approximately 50 times per second. The previous computation would be a very close estimate for the next iterative solution.

Referring to Diagram 1, and the associated simple geometry, the technique employed in the SD-4 can be summarised as:

(a) Adopt a value for K and compute d from equation (1),
(b) Use this value to compute a value for μ from equation (2),
(c) If the initial value for K was correct, μ should be equal to 1.34. (Jerlov, 1976),
(d) If the value of μ is not within reasonable tolerances of 1.34 then a new value for K is determined by multiplying K by $1.34/\mu$ and the cycle repeated.

The intial value adopted for K is 1.34 and the latest calculated value is retained as the initial estimate for the next set of iterations. Once the value computed for μ is within the pre-set tolerance, a final value for d is calculated which allows plate coordinates to be computed.

In practice, the square roots shown in equation (2) are not computed as the algorithm has been programmed using μ^2. The only occasion that an operator may notice a slowing down of the operation of the SD-4 is if the floating mark is lifted out of the water near the centre of a model and the water re-entered near the edge of the model. In this worst possible case, four or five iterations may be required before a suitable value for K is obtained and an experienced operator may notice a momentary pause as the floating mark re-enters the surface.

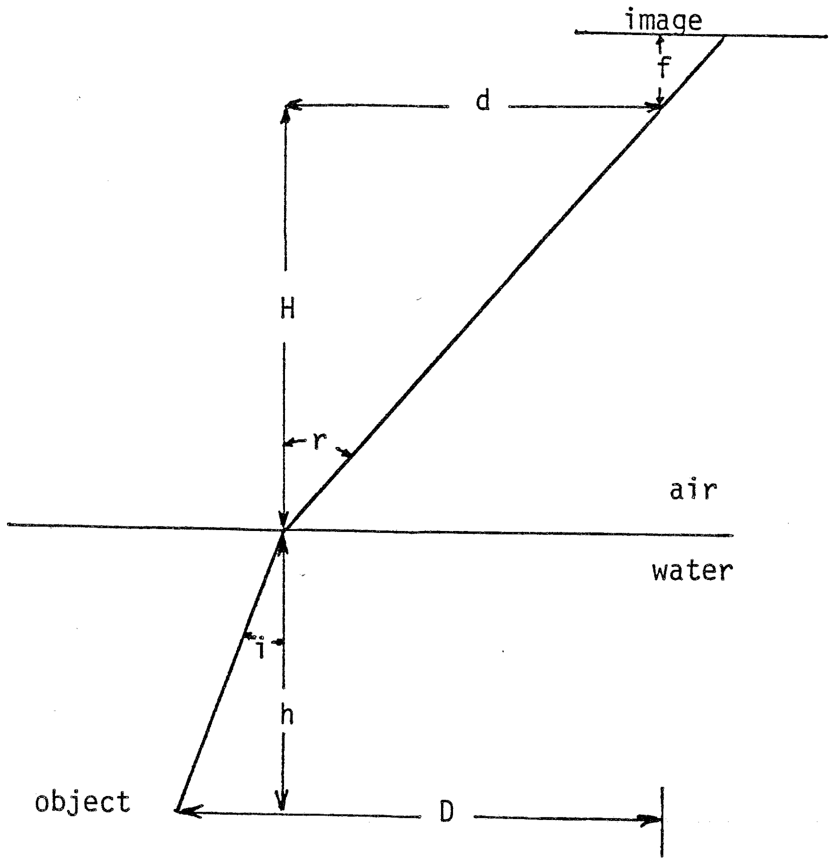


DIAGRAM 1. Two-Media Geometry

If K is the ratio of the tangents of the angles i and r then

$$\frac{D - d}{h} = K.\frac{d}{H}$$

$$\text{or} \quad d = \frac{HD}{Kh + H} \qquad .....(1)$$

If μ is the refractive index, then Snell's Law can be expressed as

$$\frac{d}{(d^2 + H^2)^{\frac{1}{2}}} = \mu \, . \, \frac{D - d}{(h^2 + (D - d)^2)^{\frac{1}{2}}}$$

$$\text{or} \quad \mu = \frac{d}{(d^2 + H^2)^{\frac{1}{2}}} \, . \, \frac{(h^2 + (D - d)^2)^{\frac{1}{2}}}{D - d} \qquad .....(2)$$

Results and Comment

The results of the independent model block adjustment indicated an accuracy of ±4.0mm in X, Y coordinates and ±14.0mm in Z. This is approximately a factor of two worse than the theoretical estimation. However, in this "practical" test, ocean swell, current surges and a sea breeze estimated at 10 knots (approx. 20km/hr) caused difficulties that are not encountered in theoretical estimations. A small part of this discrepancy can be attributed to the problems of establishing control coordinates.

The accuracy in planimetry was approximately 1:1200 expressed as a ratio of the flying height and similarly the heighting accuracy was 1:450. For many coastal engineering projects, these accuracies are much better than can be obtained by other more costly procedures.

There are several ways in which the results from non-metric photography can be improved. Fiducial marks may be arranged in the focal plane so that uncertainties in the perspective centre can be deduced and eliminated. Subsequent to the tests described, Dr. Clive Fraser (University of Calgary) suggested that small (2mm by 2mm) reference chips of perspex be glued into the corners of the image frame area of the cameras. This has been done and testing with these "fiducial" marks is proceeding.

The lens distortion parameters of Canon AF35M cameras have been determined (Fryer, 1984) and, noting the inexpensive nature of the camera (A$200), are reasonably small, with radial distortions generally less than 10µm. The SD-4 analytical stereoplotter software has provision to correct for known lens distortions.

Significant improvements in accuracy can be achieved from most non-metric photography if individual calculations of the effective focal length are made for each photograph. The variation in focal length is directly related to film unflatness and the variability of that unflatness. By observing ten or more points during the relative orientation phase, the authors feel that this problem is slight alleviated, but are continuing modifications of the SD-4 software to allow focal length computation as an option. The unflatness of the film is mainly due to a bulging near the centre and investigations into this effect and vacuum systems to correct for it are continuing at the University of Newcastle.

Conclusions

The floating pyramid structure with its associated polycarbonate trays has been shown to be an effective apparatus for obtaining through-water 35mm photography at a scale of about 1:200. Using an SD-4 analytical stereoplotter which had its software modified to provide parallax-free viewing of two-medium photography, well-defined planimetric detail was extracted with an accuracy of ±4mm and a heighting accuracy of ±15mm, despite problems of wind, ocean swell and water turbidity. The accuracy could be improved by modifications to the non-metric cameras: specifically the introduction of fiducial marks and a film flattening device. Further improvement may be obtained by computing the actual focal length for each exposure.

The technique appears to offer a practical solution for detailed mapping in shallow water.

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