The International Journal of Nautical Archaeology and Underwater Exploration (1973), **2.1**: 163–176

Technical notes

Assessment trials of underwater acoustic triangulation equipment

Introduction

One of the research projects of the Unit of Coastal Sedimentation (UCS), a component body of the Natural Environment Research Council, is the preparation of accurate acoustic mosaics of the seabed, using side scanning sonar equipment (Kelland, 1972; Kelland & Hopkins, 1972). Existing equipment, such as the EG & G Dual Channel Side Scanning Sonar, presents the results in the form of analogue records on wet electrolytic paper (Fig. 1). The scales of these records are different in each direction, i.e. are non-isometric, being governed by the sweep rate of the instrument along the sweep direction (sonar range), and a combination of the paper feed rate and ship's speed over the ground along the paper transport direction (see Fig. 1). In order to plot accurately information so recorded on these records it is necessary to correct for these scale differences. The effect of slant-range measurements along the sonar range, and the variable heading of the sonar transducer, also have to be taken into account. These various corrections are very laborious to apply if sonar records are processed by hand and interest is growing in the development of automatic processing techniques.

UCS have prepared isometric records (corrected for scale differences and heading variations but uncorrected for slant-range

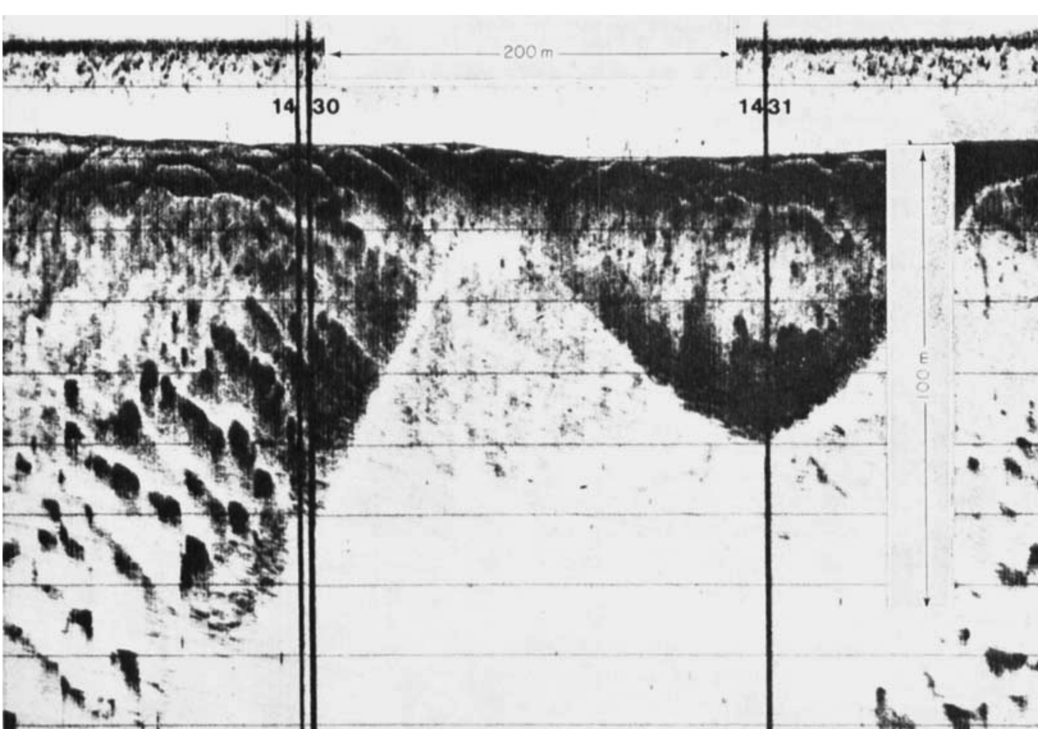

Figure 1. High resolution side scanning sonar record illustrating differences in scales along the sonar range and ship's track.

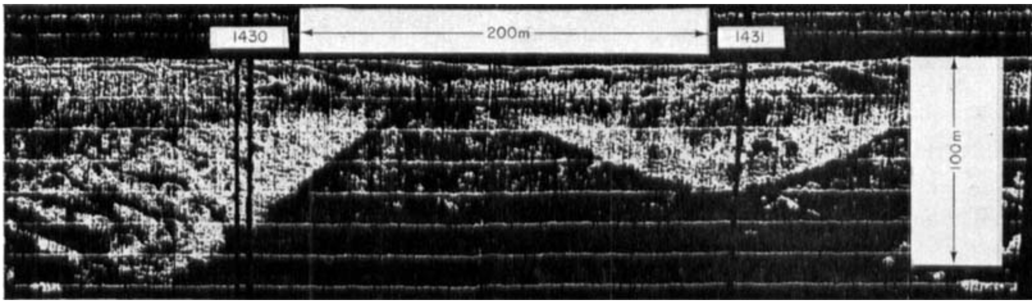

Figure 2. Isometric strip (uncorrected for slant range effects) of the sonar record shown in Fig. 1.

effects) by playing back sonar data recorded on magnetic tape using the equipment developed at Bath University. (Chesterman & Hopkins, 1971; Hopkins, 1971.) (Fig. 2.) However, the scale accuracy of the sonar mosaics which can be assembled from these isometric prints is no better than the accuracy with which the ship's speed over the ground is known. Existing electromagnetic navigation systems allow this to be determined to an accuracy of the order of 5%. In order to improve on this figure UCS intend to 'copy' airborne mapping techniques and install control points on the seabed, which will be recorded by the side scanning sonar. Corrected isometric prints will then be assembled accurately to match the known positions of the control points. The control points thus have to be accurately triangulated and it is considered that in water depths of interest to UCS this can best be carried out by suitably equipped divers.

Underwater triangulation techniques

Underwater triangulation techniques have been developed by archaeologists to map wrecks and submerged buildings. These have been based on the use of underwater tapes and/ or grids constructed over the archaeological site and are well documented in the literature. Recent work has been reported by Farrington-Wharton (Farrington-Wharton, 1970) of an underwater theodolite and by Milne (Milne, 1972; and p. 168) of underwater surveying by plane-table and alidade. But most of the survey work carried out by the Unit of Coastal Sedimentation is in areas of low visibility which limits the effective use of underwater tape measures and optical techniques. Also the seabed morphology is normally so variable that a diver could not guarantee that a taped distance represented the straight line distance between measuring points. Finally the area mapped by the sonar is too big to consider triangulating control points with tapes or grids. The Unit of Coastal Sedimentation therefore decided to evaluate a diver operated underwater acoustic measuring system being developed by Partridge of Acoustical and Electronic Services Ltd (AES) (Partridge, 1970, 1971). The equipment is

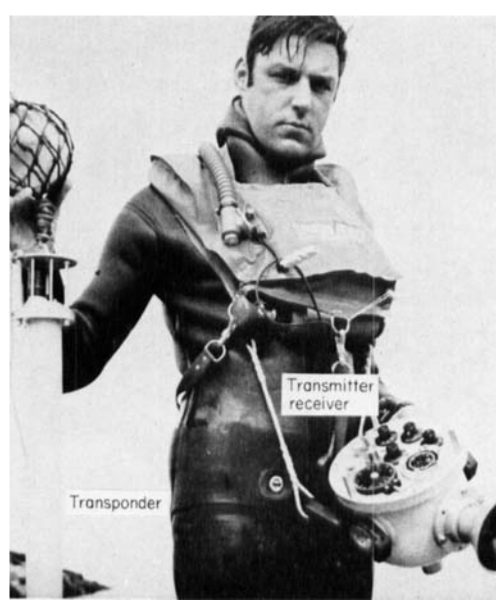

Figure 3. Diver underwater acoustic surveying equipment.

based on pulsed acoustic transmission techniques and incorporates two transponders and a diver operated transmitter/receiver (Fig. 3). The transmitter/receiver is used to measure the distance from each transponder in turn, i.e. operated in range-range modes. It measures distance by timing the interval between transmission of an interrogation pulse from the diver unit and the reception of the return signal. The display is in digital form and the prototype has a maximum instrumental resolution of 0·1 m and a maximum range in good conditions of 1000 m.

Evaluation trials

Trials were carried out during 1970 in approximately 7 m of water in Lyme Bay to evaluate the ease of operation and the accuracy of the acoustic system in comparison with underwater tape-measures, in laying out and measuring a square of approximately 30 m (Kelland, 1970). This square was selected because it could easily be established using tapes, but at the same time, the distances involved exceeded visual range and thus simulated one of the main problems of operational work. Finally, the size closely approximated the order of triangulation distances anticipated in underwater photogrammetry work, a field which is also being researched at the Unit of Coastal Sedimentation (Moore, 1972).

Two exercises were completed during the assessment trials. In the first a 30-m square was established using woven fibreglass tapes and checked by the acoustic equipment. A base-line approximately 30 m long was pegged out using tape and compass (Fig. 4). A second line was then laid out perpendicular to the base-line, as near as could be judged, to a point fixed at the intersection of two tapes run from stakes positioned at either end of the base-line, one tape being 30 m and the other 42·5 m. A third line was established in a similar way to the remaining corner of the square. The four corners were marked by metal stakes hammered into the seabed and buoyed to the surface, and the sides of the square marked out with string to facilitate re-location underwater. The four sides and

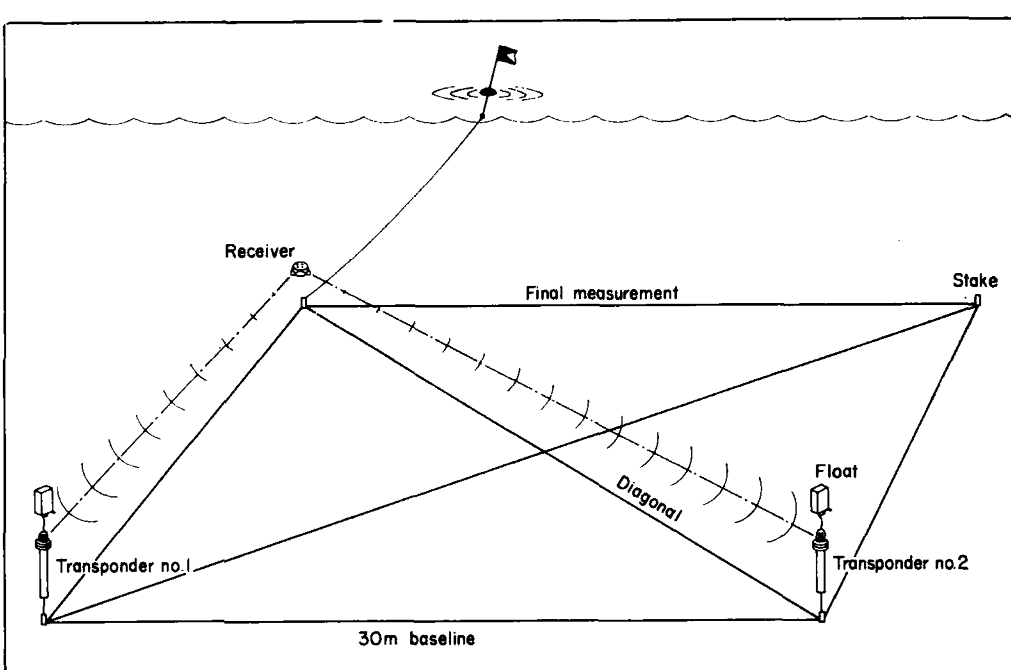

Figure 4. Underwater triangulation trials.

two diagonals were accurately taped and recorded.

These dimensions were then re-measured using the acoustic equipment by fixing a transponder to each stake in turn and measuring its distance to the remaining stakes. Temperature and salinity measurements were carried out during the acoustic work in order to determine the speed of sound in seawater.

In the second exercise, the reverse procedure was adopted and the 30-m square laid out using the acoustic equipment. The base-line was established along a known compass bearing using one transponder. A second 30 m side was positioned perpendicular to the base-line by determining the intersection point of two known position circles (30 m and 42·5 m radius) from two transponders operating at different frequencies and positioned at either end of the base-line. A third side was laid down in a similar manner and the four corners and sides marked out as described above. The sides and diagonals were then accurately measured using the receiver with one transponder which was moved from stake to stake. In this exercise it was attempted to increase the resolution of the instrument (nominally 1 digit corresponding to 1 m) by using an interpolation technique. The approximate distance—to 1 m—of a side was measured and then, using the directional properties of the receiver/transducer, the diver moved towards the transponder until the range reading reduced by one unit. The distance back to the stake was measured by tape and added to the whole unit-range reading of the instrument. Temperature and salinity measurements were taken during this stage of the work. Finally the square was re-measured using tapes.

Results

Measured values: the following columns list the taped and acoustic measurements of the two squares established during the trials. The acoustic values have been corrected for the speed of sound in seawater at the time of measurement.

Consistency check: to obtain an indication of the accuracy of the measurements an internal consistency check was made by comparing the measured values for one of the sides (CD) with that calculated from the measured values of the other three sides and two diagonals.

Diving log: a log was kept of both the total diving time and elapsed time required to complete the different stages of the trials.

Side	Taped values (m)	Corrected acoustic values (m)	Difference (m)
Exercise 1—*Taped Square*			
AB (Base)	29·34	29·31	−0·03
AC	30·02	30·06	+0·04
CD	29·29	29·35	+0·06
DB	30·14	30·06	−0·08
AD (Diagonal)	42·02	41·89	−0·13
BC (Diagonal)	42·09	42·08	−0·01
Exercise 2—*Acoustic Square*			
AB (Base)	29·90	29·88	−0·02
AC	30·07	30·06	−0·01
CD	31·25	31·16	−0·09
DB	29·53	29·58	+0·05
AD (Diagonal)	42·91	42·89	−0·02
BC (Diagonal)	42·62	42·68	+0·06

	Measured (m)	Calculated (m)	Inconsistency (m)
Taped Square			
Taped values	29·29	29·44	+0·15
Acoustic values	29·35	29·31	−0·04
Acoustic Square			
Taped values	31·25	31·45	+0·20
Acoustic values	31·16	31·50	+0·34

	Diving time	Elapsed time
Exercise 1		
Establishing the *taped square*	4 h 10 min	3 h 40 min
Measuring the *taped square* with the acoustic equipment	1 h 35 min	1 h 35 min
Exercise 2		
Establishing the *acoustic square*	2 h 26 min	2 h 25 min
Measuring the *acoustic square* with tape measures	1 h 55 min	55 min
Measuring the *acoustic square* with the acoustic equipment	1 h	30 min

Discussion

The comparison between the taped values and acoustic values for the four sides gave root mean square (RMS) errors of $\pm 0{\cdot}06$ m for the *taped square* and $\pm 0{\cdot}05$ m for the *acoustic square*. This suggests that the interpolation technique used for measuring the *acoustic square* did not improve the accuracy of the acoustic method. However, the RMS value is increased by the comparatively large difference in the readings for side CD ($-0{\cdot}09$ m). If this value is ignored as suspect the RMS difference is improved to $\pm 0{\cdot}03$ m.

The inconsistency in the taped measurements (*taped square* $+0{\cdot}15$ m: *acoustic square* $+0{\cdot}20$ m) can be explained in part by an unknown error in the measurement of the diagonals. This arose because the 30 m fibreglass tapes had to be extended by a 20 m terylene rope for these particular measurements. The extension rope was found to shrink when wet by up to 0·1 m. It can be shown that the calculated value of the fourth side would be too great by a factor:

$$2 \times \frac{\text{diagonal length}}{\text{base length}} \times \text{error in the diagonals.}$$

For a measured maximum shrinkage in the extension rope of 0·1 m and diagonal and base measurements of 42·5 and 30 m respectively the maximum error in the calculated value for CD is 0·28 m. (Shrinkage was not taken into account in the calculations due to uncertainties in the rate of shrinkage.) Other errors contributing to the inconsistency in the taped values arise from applying different pulling tensions during the measurement of each side, and the possibility of the tapes not being in a straight line over their whole length due to the effects of currents.

It is difficult to explain the increased inconsistency of the acoustic values obtained measuring the *acoustic square* compared with those obtained on the *taped square* ($+0{\cdot}34$ m compared with $-0{\cdot}04$ m), because the interpolation technique used in the former case was expected to improve the accuracy of the method. A contributing factor could be the suspect value for CD referred to above. However, it is to be expected that the acoustic system should be more inaccurate than tapes over short distances over flat seabeds due to inherent resolution limitation of the equipment (finite system bandwidth) and plumb-line errors caused by displacement of the transponders from the marker stakes by currents. Taking into account the difference between the taped and acoustic measurements of the four sides and the inconsistencies in both squares it is considered that the acoustic system measurements are significant to 0·10 m.

A significant decrease in diving time (approximately $1\frac{3}{4}$ hours) was achieved laying down the *acoustic square* compared with the *taped square*. The beneficial effect of practice is shown by the decrease in the time taken to make the accurate acoustic measurements during the second exercise. The acoustic system was also easier to use as there was no need to drag tapes over the seabed or to check for 'straightness' and the absence of kinks due to snagging on seabed objects.

Conclusions

It is considered that the assessment trials were successful and that the results justify more detailed trials. UCS are discussing with AES Ltd an improved underwater acoustic measuring system which will have increased resolution and be easier to handle and read than the prototype equipment. Further trials of this new system will be held in the latter part of 1972 and during 1973. These will be carried out over various types of seabeds (rocks, clay etc.) and in areas of dipping seabeds and over seabeds with irregular morphology. In the last two cases it will be necessary to combine the distance measurements with height measurements in order to correct for slant range measurement.

It did prove feasible to establish an accurate square, but it was much simpler and less time consuming to peg out an approximate square and then accurately measure the sides.

The present acoustic equipment gave results over the short distances measured which were no more than 0·1 m different from those obtained by tape. The internal consistency checks were better than a third of a metre. Although these figures are large compared with figures obtained in terrestrial surveying, it is doubtful if similar accuracy could ever be achieved underwater in low visibility. However, it is hoped that improved accuracy and better operational techniques will be achieved in the future trials. The acoustic method showed operational advantages over the tape method by economizing on the number of divers and diving time involved. These advantages would be even more noticeable at greater ranges where the use of tapes becomes completely impractical.

The successful development of this equipment, and a proper understanding of the limitations of the technique, should prove to be of considerable value to the archaeologist and civil engineer interested in obtaining detailed plans of man-made objects on the seabed. It will also be very useful for the hydrographic surveyor or scientist who wishes to construct accurate acoustic sonar maps of small parts of the sea floor.

Acknowledgements

The author thanks J. Partridge for loaning the equipment and for taking part in the trials; his diving colleagues at UCS, J. Moore, and J. Malcolm, for their contribution to the project; and P. Hooper for assembling the isometric strip shown in Fig. 2.

References

Chesterman, W. D., & Hopkins, J. C., 1971, Recent results from an isometric side scan sonar system. *Ultrasonics Conference*, Sept. 1971: 3–5.

Farrington-Wharton, R., 1970, The development and use of a practical underwater theodolite. *Proc. Inst. Civ. Engrs.*, **45**: 491–506.

Hopkins, J. C., 1971, Tape recording of side scanning sonar signals. *Int. Hyd. Rev.*, **49**(1).

Kelland, N. C., 1970, Initial assessment trials of a diver operated acoustic measuring system, *UCS Internal Report*, 70/6.

Kelland, N. C., 1972, Preparation of isometric records from high resolution side scanning sonar data using the Bath University playback equipment. *UCS Internal Report*, 72/23.

Kelland, N. C. & Hopkins, J. C., 1972, Making mosaics of high resolution side scanning sonar. *Offshore Services*, Oct.: 34–35.

Milne, P. H., 1972, In situ underwater surveying by plane table and alidade. *Underwater Journal*, **4**(1): 59–63.

Moore, J., 1972, Feasibility study for underwater photogrammetry. *UCS Internal Report*, 72/8.

Partridge, J., 1970, Electronic aids for exploration divers. *Proc. IERE Symp. on Electronic Engineering in Ocean Technology, Swansea*, Sept.: 423–46.

Partridge, J., 1971, Precise underwater navigation. Offshore Survey and Inspection Conference. Great Yarmouth. *Hydrospace*, Oct.

N. C. Kelland

Unit of Coastal Sedimentation,
Beadon Road, Taunton

Underwater surveying at Gulber Wick in Shetland

From 29 June to 19 August 1972 an expedition investigating Viking sites in a marine environment was undertaken under the leadership of Robert Farrell, Ian Morrison, Alan Bax and James Gill. The purpose of the expedition was to search for archaeological remains in Gulber Wick Bay just south of Lerwick. The second objective was to investigate the possibility of survival of artefacts offshore at Jarlshof and to study the marine environment of that site in Viking times. A force of 40 to 50 divers was employed and a number of scholars aided the work at various stages during the summer. Dr Peter Milne of Strathclyde University provided underwater plane table surveys of parts of the Gulber Wick site; Dr and Mrs Duncan McArdle of Edinburgh helped both in the underwater work and in the discovery of a number of land sites n the vicinity of Gulber Wick. The materials which were collected are still being evaluated; but it is just possible that one or two pieces from the Viking period may have been discovered though this will not be known until laboratory tests are completed. At Jarlshof the nature of the site was such that there is no chance for survival of artefacts from the early period because of the sea conditions and the nature of the sea bottom. There are some indications of the possible extent of the site in Viking times and a geomorphological report is to be prepared by Dr Ian Morrison. The Gulber Wick site has been surveyed and almost all possible search areas have been at least sampled; there remains some further work on this site involving more sophisticated search and excavation methods.

R. T. Farrell, Cornell University