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CORRELATION OF SURFACE AND UNDERWATER POSITION FIXING TECHNIQUES

by Dr P.H. MILNE (*)

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SYNOPSIS

Underwater acoustic position-fixing systems developed rapidly in the 1970's to meet the demand for more precise offshore survey work in connection with the development of North Sea oil. However the accuracy of an underwater position-fix depends on the correlation of the surface and underwater navigation systems employed, and the precise deployment of the seabed transponders. It is thus important to study the multipath propagation of the acoustic signals to limit range errors.

To assist offshore operators involved in diver or submersible tracking in the vicinity of offshore structures, the problems of platform navigation and surveying have been fully researched and a system developed for the precise orientation of a diver or submersible during a platform survey. The presently developed deep-water position-fixing system is based on a stand-alone desktop mini-computer which will accept up to seven data inputs including the underwater acoustic slant ranges for subsequent evaluation to give an underwater position-fix in three dimensions (3D). The software has been designed principally for underwater navigation, and surveying, but will also accept surface radio position-fixing signals, thus saving initial set-up time as only one computational system is required. The results of underwater surveys are presented.

(*) Department of Civil Engineering, University of Strathclyde, Glasgow, Scotland.

INTRODUCTION

The offshore survey industry was required to expand rapidly in the 1970's to cope with the increasing extraction of hydrocarbons, especially in the North Sea. Since time is money to the oil industry, offshore surveys and positioning services have had to be carried out with the maximum of speed and accuracy. Thus in recent years offshore survey and position-fixing techniques have become increasingly sophisticated.

An offshore survey team has a choice of three position-fixing systems :

1. Satellite navigation,
2. Radio-positioning from shore stations,
3. Underwater acoustic navigation from seabed transponders.

For standard hydrographic survey work the choice of either satellite or radio position-fixing systems will depend on the distance from the coastline and the overall accuracy required. Where precise seabed surveys are required for underwater pipelines or offshore platform investigations the use of underwater acoustic navigation has considerable advantages since the location of a towed sensor or submersible can be located readily (MILNE, 1980b). However, the accuracy of the underwater position-fix will depend on the correlation of the surface and underwater navigation systems employed, and the precise deployment of the seabed transponders. This correlation has become of increasing importance due to the expansion in the use of divers and submersibles in underwater inspection and maintenance programmes for the certification of platforms in the North Sea (MILNE, 1980a). Precise underwater position-fixing is essential when unmanned submersibles are in operation to prevent the entanglement of the umbilical cable especially in the vicinity of offshore platforms (MILNE, 1979).

SURFACE POSITION-FIXING

Radio position-fixing systems have been in operation for over twenty years in the North Sea and combine a good operating range from shore stations with a good update. Such systems either operate using the hyperbolic lattice method or the range-range method, and on larger survey vessels the two methods can often be combined (MILNE, 1980b).

For offshore operations far from land, or where no shore-based radio position-fixing chain exists, satellite position-fixing has considerable advantages. The American Navy Navigation Satellite (NNSS) system, sometimes better known as *Transit*, has been commercially available since 1967 and, although primarily intended for ship navigation, is now playing an increasing offshore role in geophysical exploration, site suitability surveys, cable laying, deep-sea mining and oceanographic research. This involvement is expected to increase when the Navstar satellite position-fixing system comes into operation in the late 1980's.

Unlike radio position-fixing, a satellite position-fix can only be obtained every one or two hours, during a satellite pass. In the static mode, for example on a drilling rig, to find the precise position of a wellhead, this may be acceptable, but in the dynamic mode it is essential to track the vessel at all times using either a radio position-fixing system or an underwater acoustic navigation system.

UNDERWATER ACOUSTIC NAVIGATION

In the 1970's underwater engineering work offshore stimulated the demand for underwater navigation systems for use by divers and submersibles. Systems for ship navigation offshore are often a combination of surface and sub-surface techniques (fig. 1). Where underwater work is concerned there are only two methods, either dead reckoning or acoustic navigation.

At present there are several underwater acoustic navigation methods available depending on whether divers, manned or unmanned submersibles are em-

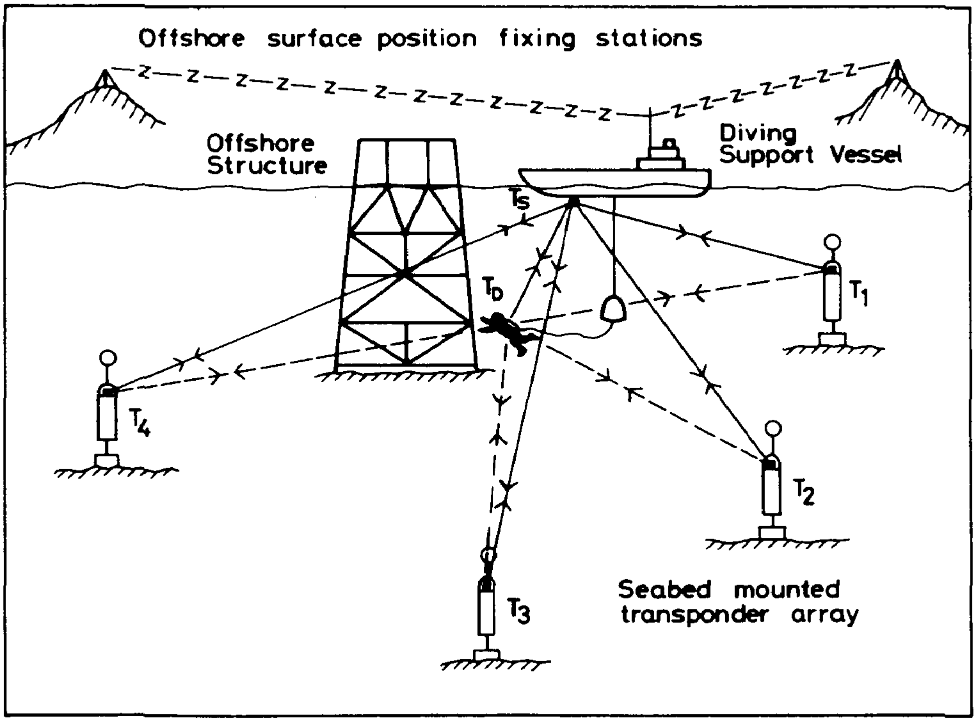

FIG. 1. – Underwater LBL acoustic navigation system with either a surface transducer, T_s, or a diver/submersible transducer, T_D, using a seabed mounted transponder array T_1 to T_4. From MILNE (1980a), reproduced by kind permission of BPS Exhibitions Ltd.

ployed. Although the term navigation essentially implies the movement of a ship, in the underwater connection it is often expanded (Westwood, 1978) to include:

(i) Tracking, e.g. a submersible tracked by a mother-ship along a pipeline.
(ii) Positioning, e.g. a diving bell positioned relative to a work site for welding or repair.
(iii) Measurement, e.g. the precise surveying of the seabed, or distance measurement between pipe ends and risers.

Each of these activities requires a varying degree of accuracy, since for site surveys and pipeline tie-ins, highly accurate navigation is required, whereas a lower precision is often acceptable for a pipeline inspection.

Acoustic navigation systems are generally classified by the length of their baselines; that is, the distance between the elements of the transmitter or receiver array. There are three main baseline classifications:

	Approx. array distance
1. Short baseline (SBL)	~5-20 m
2. Super-short baseline (SSBL)	<0,5 m
3. Long baseline (LBL)	>20 m

Both surface and subsurface vessels can use such underwater acoustic navigation techniques. With the development of the mini-computer and more advanced signal processing techniques, it has now become possible to place an array of several transponders on the seabed and to automatically process the slant range information received at the surface vessel from all transponders simultaneously. The vessel's position relative to the transponder array is then calculated automatically.

The SBL and SSBL systems are quick to establish since the transmitter/receiver array is normally mounted in the hull of the vessel. Unfortunately, both systems are susceptible to acoustic-signal-path interference in the vicinity of offshore structures, and LBL systems are to be preferred. Some commercial operators have overcome this problem by combining the benefits of both SSBL and LBL systems. An example of a combined system is Honeywell's RS/900 acoustic position indicator (Neudorfer, 1978), where, on a routine pipeline inspection, the surface vessel can use the LBL system for navigation and at the same time use the SSBL system to track a submersible.

If seawater was a uniform isotropic medium, underwater acoustic navigation using transponders or beacons would lose much of its complexity. This, of course, is not the case and it is necessary to take account of sound-wave refraction effects in the design and operation of the system (Green, 1979). Also, since the velocity of sound in seawater is affected by changes in temperatures, pressure and salinity it is essential prior to carrying out precise underwater acoustic measurements to check on the velocity of sound. This can be achieved either using a velocity meter or by carrying out temperature and salinity profiles of the area.

The operational range and accuracy of underwater acoustic navigation systems depend on the frequency of the acoustic pulses. In general, the higher the frequency of the system the better the overall accuracy. However, the higher the frequency, the lower will be the range; for example, a frequency of 10-20 kHz *will give a range of 10 km, whereas a frequency of 300 kHz will only give a* range of 400 m. Although the higher frequency systems give better accuracy, they require high frequency generators and large power supplies, with consequent increases in size and cost. Frequency selection therefore has to be considered from the following factors such as cost, size, range, accuracy and application.

The overall accuracy of an underwater acoustic navigation system depends fundamentally on two aspects : firstly, the accuracy of the establishment of the transponder navigation array and, secondly, the determination and study of multipath propagation to limit range errors.

A LBL transponder array may incorporate only two or three transponders or may be a very extensive network, for example, along a pipeline route. These transponders have to be installed on the seabed or underwater structure either by surface vessel or submersible. The network of transponders is then located geographically using radio-positioning or satellite navigation equipment. However the geographical co-ordinates found at the time of implanting the transponders on the seabed are generally of too low an accuracy for precise navigation, often ranging from ± 10 m to ± 50 m. It is therefore necessary to carry out a three-transponder survey to determine the precise seabed co-ordinates of the transponders. This is normally carried out by steaming in a clover-leaf pattern round the transponders and obtaining precise measurements from at least six locations.

Although it is possible to use completely separate surface and underwater acoustic position-fixing systems it is preferable to use an integrated system like the Decca OASIS system (Offshore Acoustic/Satellite Integrated System) using a mini-computer to integrate the Aqua-Fix and Sat-Fix satellite navigation fixes (*Offshore Engineer*, 1979). Other similar systems are AUTRANAV and SEANAV (MILNE, 1980b).

SUBMERSIBLE AND DIVER TRACKING

Up until 1977 the major application of underwater acoustic navigation was for manned submersibles. Since then, however, there has been a continuous expansion in the operation of remote controlled vehicles or unmanned submersibles requiring more precise navigating techniques, especially in the vicinity of offshore structures for underwater inspection and maintenance (MILNE, 1978).

Vehicle navigation requirements vary from operating small observation vehicles, like Hydro Products' *RCV-225* to larger work vehicles like Sub-Sea Surveys' *Consub 2*. In general, for open water or site navigation it is essential to :

(i) Determine the position of the submersible relative to its mother-ship.
(ii) Plot the position of the umbilical cable if possible.
(iii) Determine the submersible's final geographic position for plotting and logging data, e.g. pipeline position or geophysical data.

Offshore platform inspection is one of the biggest potential markets for unmanned submersibles (WESTWOOD, 1978), and here precise navigation is essential to avoid collisions with the structure and entanglement of the umbilical. Such are the constraints of platform navigation that ideally a system should be capable of:

a) Fitting to a diver or submersible, i.e. small
b) Tracking the diver or submersible around and within the structure
c) Tracking the umbilical cable
d) Fitting of obstacle avoidance sonar in the case of unmanned submersibles
e) System knowledge of the structure geometry for comparison with obstacle avoidance sonar i.e. mimic display
f) Accurate navigation to ± 0.1 m
g) Matching the navigation performance to an unmanned vehicle's dynamic responses.

DEVELOPMENT OF SARAH UNDERWATER POSITION FIXING SYSTEM

To assist operators in the underwater inspection and repair of offshore structures, research has been carried out at Strathclyde University into the problem of platform navigation and surveying, especially the correlation of surface and underwater position-fixes. A combined system was thus developed by the Department of Civil Engineering to cater for the precise orientation of a diver or unmanned submersible and subsequent underwater inspection records. The position fixing and orientation system is called SARAH (Strathclyde Acoustic Range and Height) (fig. 2), and is associated with a closed circuit television (CCTV) unit

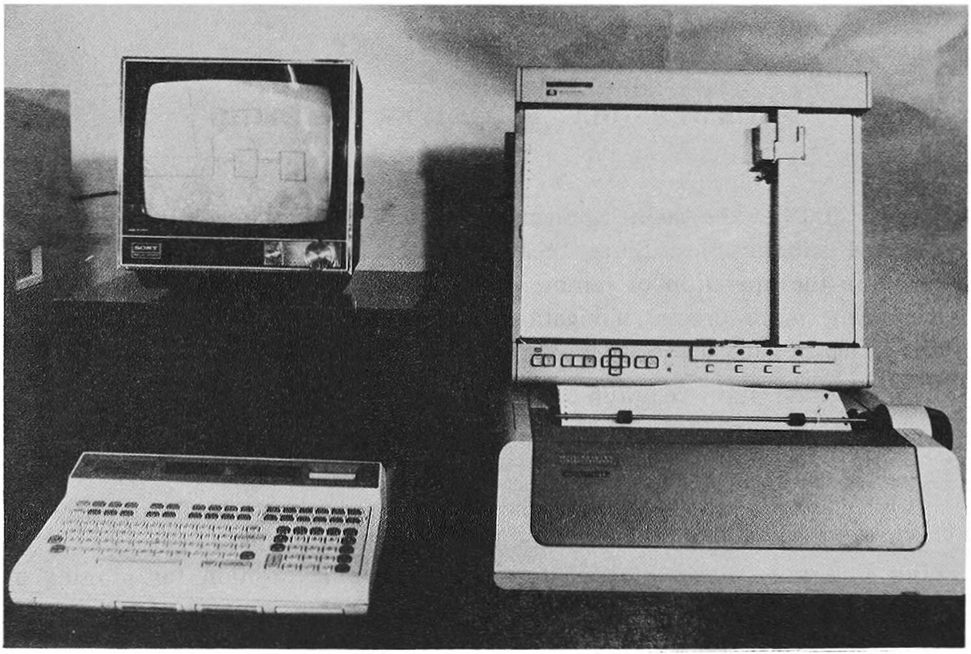

FIG. 2. – Details of SARAH hardware showing Desktop Mini-Computer, printer, graphics plotter and CRT display.

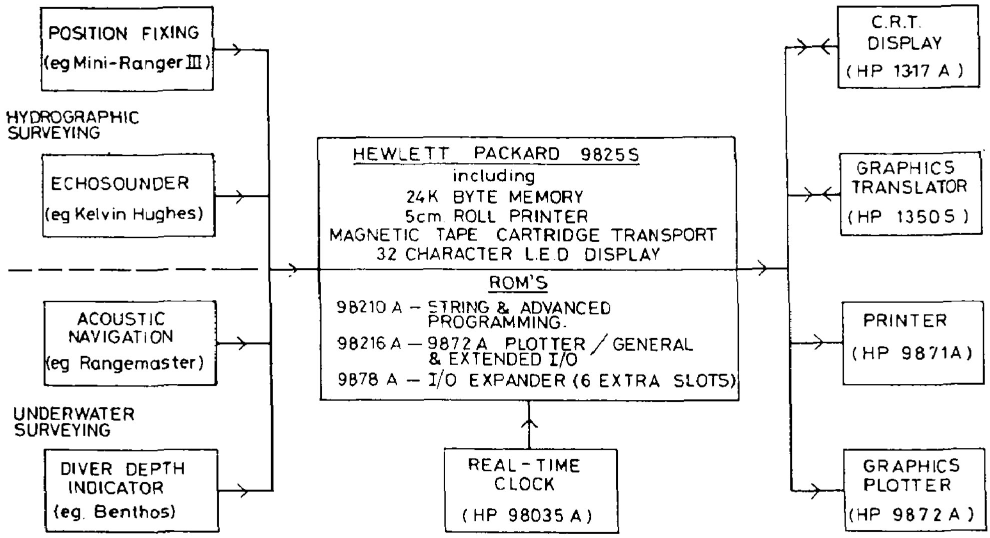

FIG. 3. – Block diagram for SARAH Desktop Mini-Computer system based on HP9825S. Up to 7 inputs can be read and 14 output peripherals controlled using an HP-IB interface. From MILNE (1980a), reproduced by kind permission of BPS Exhibitions Ltd.

called SIMON (Strathclyde Inspection, Maintenance or Navigation); the latter described in an earlier paper (MILNE, 1980a).

The SARAH system is based on a Hewlett-Packard HP Desktop Mini-Computer (fig. 3), and the software designed principally for underwater navigation and surveying in conjunction with surface position-fixing equipment. This has considerable advantages since only one computational system is required from the initial placement of seabed transponders, right through to the underwater navigation tracking.

Software programs have been developed for the computation of x-y-z co-ordinates from the input data (fig. 3) for print-out on the HP 9871A line printer (fig. 2). Given the initial configuration of a structure, e.g. 3-D co-ordinates of the steel members, etc., it is possible to obtain on the CRT display a selection from the following : x-y plot, x-z plot, y-z plot or a 3-D image.

The structure or object on the CRT screen can then be displayed from any viewpoint, once α, the rotation of the object about the z-axis, and β, the angle of tilt of the line of sight have been chosen (MILNE, 1979). Once the desired view has been generated on the CRT display, a hard copy can be obtained on the HP 9872A plotter (fig. 2).

Underwater trials with SARAH system

To test the SIMON and SARAH systems, sea trials were conducted in May 1978 and May 1979 at the Inverkip Power Station Jetty in the Firth of Clyde in Scotland. This jetty lay close to the University in water depths of 30 m and consisted of a mixture of vertical and inclined 0.6 m diameter piles providing a

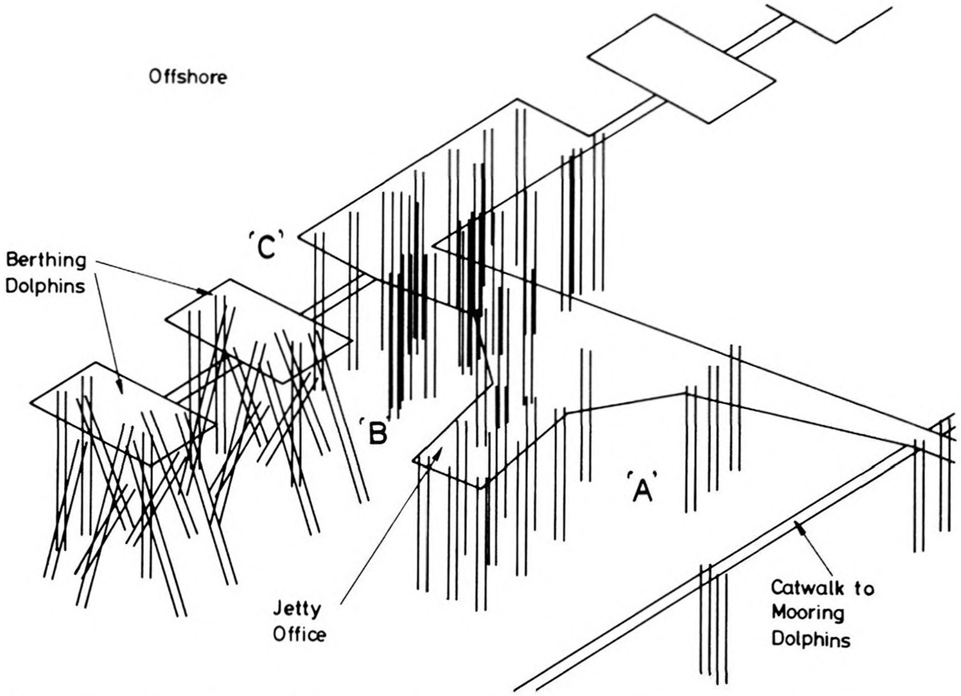

FIG. 4. – Hard-copy of SARAH-generated CRT display of piles in berthing dolphins and under jetty office.

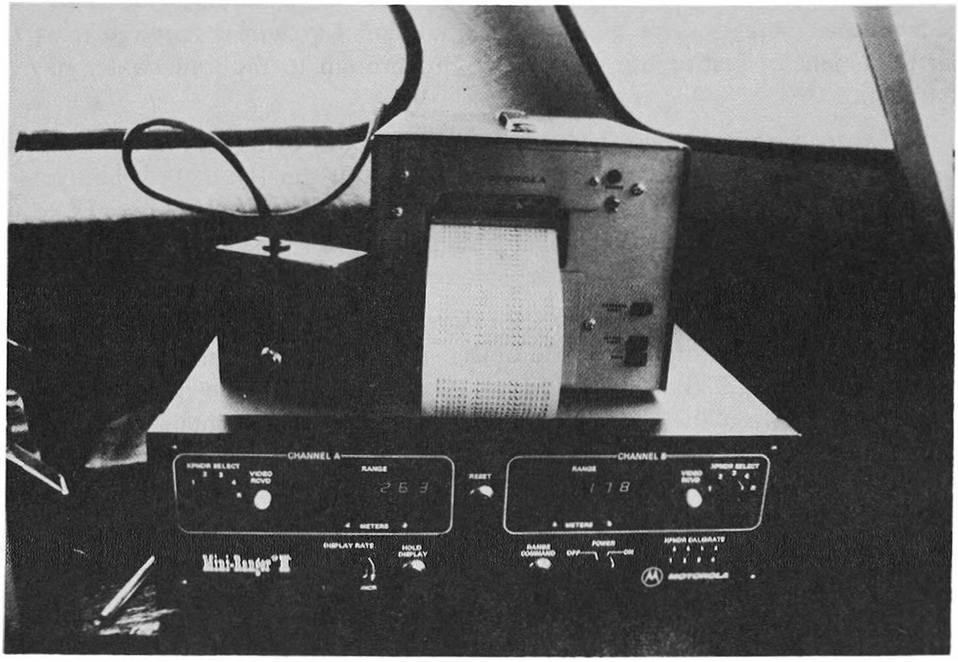

FIG. 5. – Motorola Mini-Ranger III with real-time clock and digital printer on board R/V *Strathclyde* at Inverkip.

myriad of surfaces for multi-path reflections to test the accuracy of the SARAH system. A SARAH-generated CRT display of the jetty structure showing the inclined piles used in the berthing dolphins and the vertical piles under the jetty office are shown in figure 4.

Similar 3-D plots can be obtained for any coastal or offshore structure for diver or submersible tracking provided platform co-ordinates, levels and dimensions are available from record drawings. As the 3-D plot of a complete structure is often confused, it is possible to simplify this with the SARAH software by enlarging small sections of the structure.

During the Inverkip survey a Motorola Mini-Ranger III (fig. 5) was used for the surface position-fixing of R/V *Strathclyde,* a 5.2 m inshore hydrographic survey launch. Hard copy records were obtained during the survey operations with the addition of a real-time clock and digital printer.

Underwater position-fixes were obtained by combining the underwater acoustic signals from a Sonardyne Rangemaster model « MF » with a Benthos diver depth indicator (fig. 6). The Rangemaster console with controls allows four of the slant ranges (fig. 1) to the interrogated transponders to be displayed at any one time. This is a medium frequency version of the Rangemaster acoustic navigation system and operates in the range 18-36 kHz with twelve channels switch tuned. Although a position-fix can be generated from only three transponders, it is advisable to have a built-in redundancy and hence a minimum of four transponders. T1-4 are normally deployed (fig. 1). At Inverkip the four frequencies employed ranged from 29-32 kHz and two interrogation transducers were

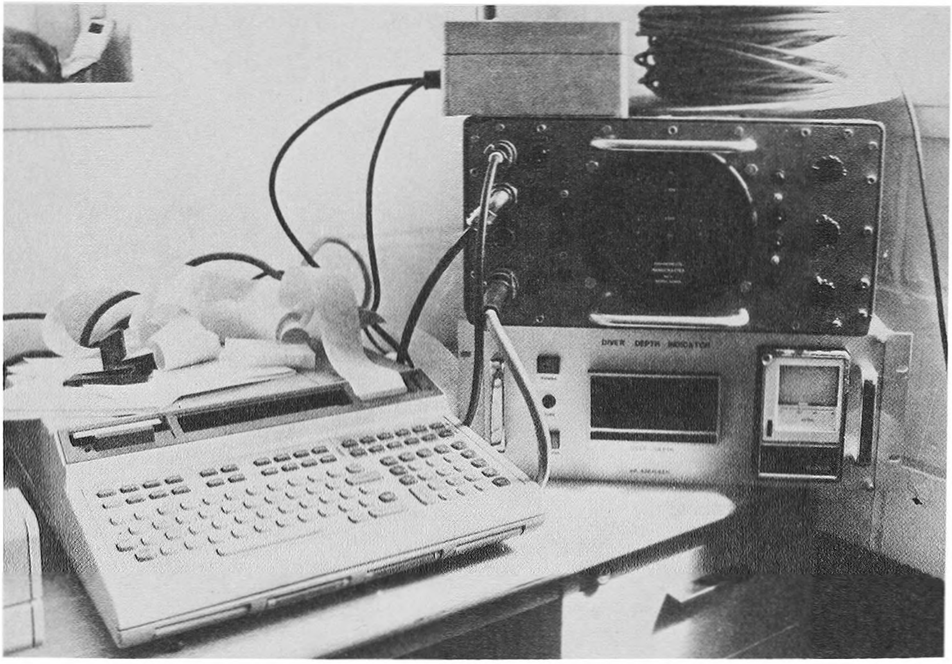

FIG. 6. – Sonardyne Rangemaster 'MF' Console with four slant ranges shown in circular display panel. The Diver Depth Indicator used to monitor the transducer depth is also fed directly into the HP9825S.

used (fig. 7). The larger dunking transducer, T_S, was used for surface position fixing and the smaller compact transducer or responder, T_D, for fitting to the diver's back-pak as shown in figure 8. The roles of all three units are depicted graphically in figure 1, meeting the requirements of a small transducer, T_D, for fitting to a diver or submersible.

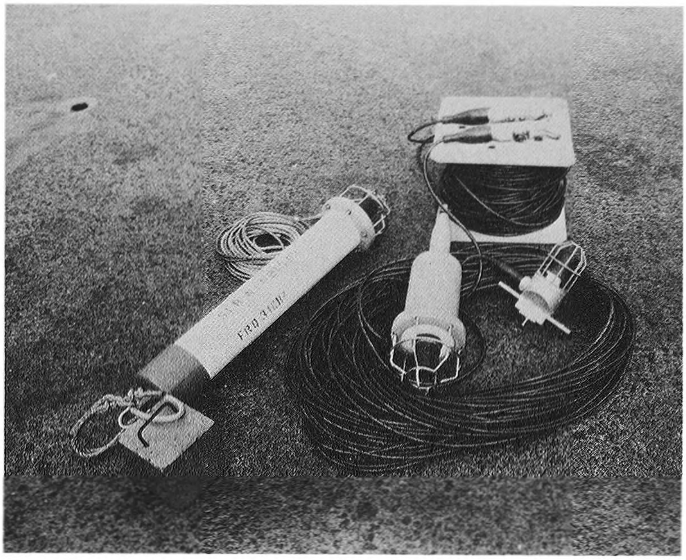

FIG. 7. – Sonardyne transponder (left) with dunking transducer, T_S, in centre and diver/submersible mounted transducer, T_D, on right, used during underwater acoustic navigation trials at Inverkip.

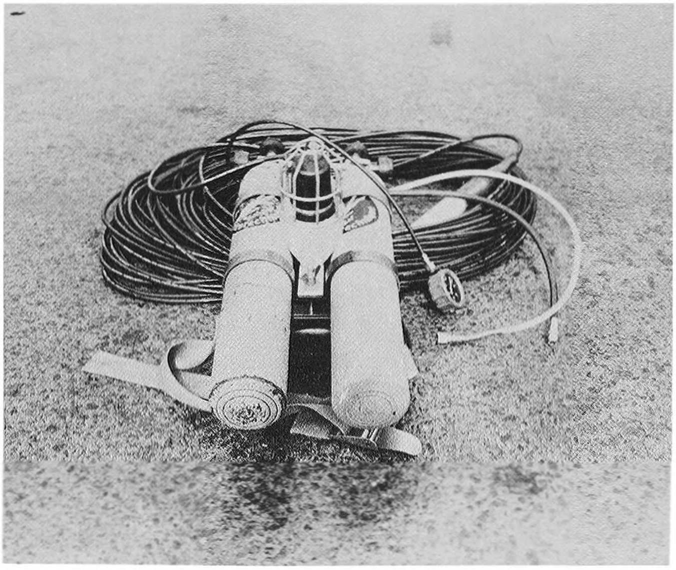

FIG. 8. – Twin bail-out bottles in back-pak for surface demand/demand diver including underwater acoustic transducer, T_S, for SARAH position-fixing system.

The advantages of a medium frequency system over a low frequency system are less susceptibility to noise in shallow water operation, but with an improved range resolution at up to distances of 3 km under favourable conditions. In figure 1 the seabed transponders T_1 to T_4 can be used for navigation by either the surface transducer, T_S, or the diver/submersible transducer, T_D. In coastal waters, or where there is a temperature or salinity gradient in the water column, the surface to seabed slant ranges using a 'sing-around' system are more liable to error than slant ranges measured at depth. Thus only seabed slant ranges were measured to the diver in the 1979 acoustic navigation trials.

After initial underwater acoustic tests in the 3.5 m deep University Diving Tank, the system was evaluated at Yorkhill Basin on the River Clyde to depths of 10 m in the vicinity of masonry and concrete dock walls. Once these tests were complete, both the SIMON and SARAH systems were transported to Inverkip to commence sea trials.

At the outset a short hydrographic survey was carried out by R/V *Strathclyde* to check on seabed depths and the ambient seawater temperature and salinity. Prior to each day's acoustic measurements a check was made on the seawater temperature and salinity to check on the correct value of the velocity of sound to be used in the slant range computations. The four seabed transponders were deployed round the jetty, one at each of the end mooring dolphins, approximately 432 m apart, and the other two just north and south of the jetty office (fig. 4) where the SARAH system was installed.

Three areas were selected for underwater acoustic navigation trials, each in areas of increasing blanketing from the four transponders:

A. between the jetty office and the catwalk
B. between the jetty office and the berthing dolphins, and
C. between and offshore of the berthing dolphins.

The first set of trials in area A were very successful. Eight points were chosen along a given transit and out of a total of 100 position fixes only 8 were outwith a band ± 0.5 m wide. The main criterion of an acoustic navigation system is to be able to send the diver or submersible back to a specific point rather than just knowing the track followed, and this was achieved.

The second set of trials in areas B and C were in very confused areas as they were surrounded by steel piles. Initial results were very poor, but by moving one of the central transponders nearer to the area of interest the results achieved gave accuracies of better than ± 1 m over 80 % of the fixes. A plot of the diver's position during an underwater inspection in area C is shown in figure 9. During the 20-minute dive, recorded by the SIMON CCTV system, fixes were obtained at approximately half-minute intervals. The track of the diver is shown leaving the diving support vessel across to inclined Pile No. 132, then moving over to inclined Pile No. 130 which was followed down to the seabed at a depth of 16 m. A previous SSEB hydrographic survey had shown an anomaly (high spot) just offshore of the berthing dolphins, and the dive proceeded offshore. However, the seabed sloped steadily into deeper water with no apparent high spots. The dive continued at a depth of 20 m along the front of the berthing dolphins and back to vertical Pile No. 90 and thence back to the ladder on R/V

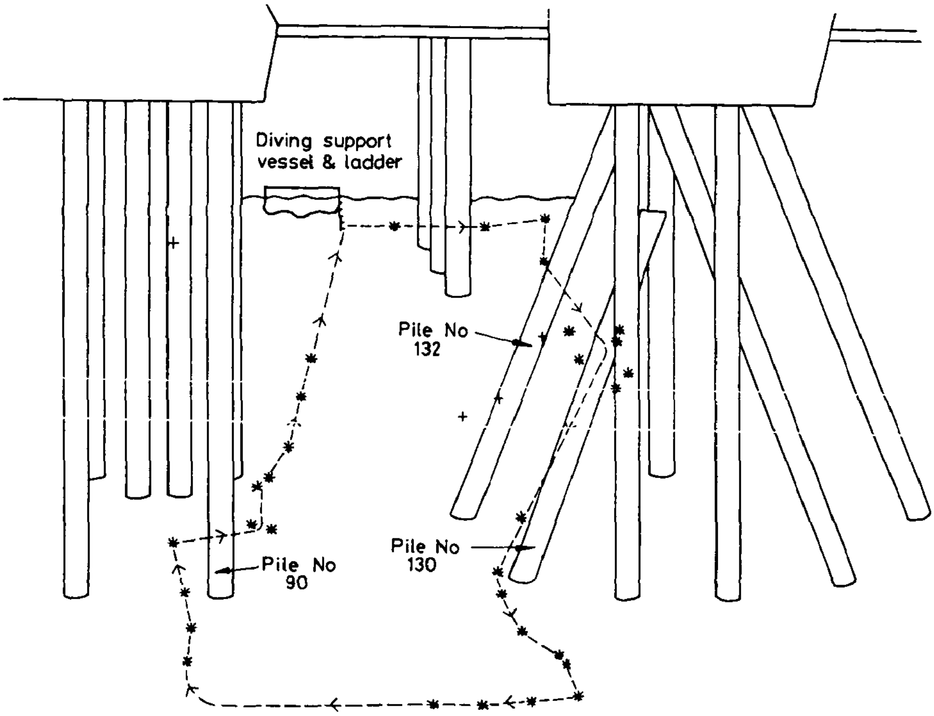

FIG. 9. – Hard-copy of enlarged CRT display of berthing dolphins at Inverkip from offshore with hidden lines removed. The location of the water surface and diving support vessel has been added and the track of diver shown by – – – –. The diver fixes where accuracy was less than ± 1 m are shown thus (+). From MILNE (1980a), reproduced by kind permission of BPS Exhibitions Ltd.

Strathclyde. Out of a total of 39 fixes only 3 computations were outside the plotting area, and 4, as shown (+) in figure 9, were plottable but with greater than a ± 1 m error. This overall 82 % acceptance was considered good in such a confused mass of steel piling at various angles of inclination, presenting the worst possible combination of shallow water and multipath reflections.

FUTURE RESEARCH ON SUBMERSIBLE AND DIVER TRACKING SYSTEMS

Although the present SARAH position-fixing system, in conjunction with either the Rangemaster or the SEANAV system, can be considered extremely useful in the vicinity of coastal and offshore structures, it is still not of sufficient accuracy to meet the earlier ideals of a tracking system. To improve this accuracy to the ideal of ± 0.1 m within a structure, future research at Strathclyde University is focussing on the development of a more accurate, microprocessor based underwater acoustic tracking system (MACLEOD *et al.*, 1979). A computer simulation is also being carried out to determine the ideal location of the LBL baseline transponders to ensure that the submersible or diver is always under surveillance. It is anticipated that apart from a few permanently based transponders, several small portable transponders would be utilised and moved round the structure to each operational area, as happened at Inverkip. Considerable interest has been shown in this research programme by offshore operators and industrial acoustic navigation firms, and joint collaboration is in prospect for 1980/81.

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