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A NON-INTRUSIVE TRACKING TECHNIQUE FOR DOLPHINS INTERACTING WITH A PELAGIC TRAWL USING A SPARSE ARRAY OF HYDROPHONES

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1. INTRODUCTION

Underwater acoustic tracking techniques have been in existence for many years, Milne[1]. Most rely on an active acoustic source triggering replies from an array of transponders, Leroy et al [2]. In cases where the tracking equipment must remain passive, the transponders are replaced by hydrophones. Research is being carried out at Loughborough University to develop systems which can passively locate and track echo-locating cetaceans. Using algorithms developed for diver tracking, Hardman and Woodward [3], a three-dimensional sparse array of four hydrophones can be used to produce these tracks. The purpose of this work is to design and develop a system that can be used for studies aimed at reducing the by-catch of cetaceans in fishing nets, particularly in pelagic trawls; the research is part of the European Commission *AIR-III* CETASEL project, De-Haan et al [4].

The objective is to attach the array on, or near, the trawl such that the tracks of echo-locating cetaceans can be monitored and analysed, thus leading to a better understanding of their behaviour; at a later stage, the aim is to devise methods of affecting the animals' behaviour to reduce their by-catch. The initial system was attached to an ROV using a fibre optic cable to transmit four channels of timing data to the ship. This system relied on the ROV being near the trawl whenever dolphins were sighted, which was often impractical because according to the evidence of by-catches the majority of cetaceans are caught at night, Morizur et al [5] when it is perilous to fly the ROV near the trawl. The ROV hydraulics also proved to be a broadband noise source that swamped any cetacean echo-location clicks, rendering the tracking array useless. In a subsequent arrangement, the array was attached to the trawl itself. Due to the turbulent nature of the water flow around the trawl a 'flat' array had to be used. The bandwidth limitations of the new transmission link, a coaxial cable, led to the use of a look-up table to determine positions. This paper describes the technology of the new system and the position-fixing algorithms associated with it.

2. THE FLAT ARRAY TRACKING SYSTEM

The new approach to the passive tracking of echo-locating cetaceans involves the use of four hydrophones because of the need for tracking in three-dimensional space, Hardman and Woodward [3], Morphett et al [6], Woodward and Coggrave [7]. The limitations of deploying the system mean that all four hydrophones are necessarily in the same plane, which obviates the possibility of three-dimensional tracking. The algorithm adopted depends on the premise that positions in 3-dimensional space can be determined from intersecting parabaloids, each representing a constant time difference between clicks arriving at a given pair of hydrophones.

Fig. 1 illustrates how parabolic loci are formed in two dimensional space for the arrival time difference between each pair of hydrophones. In Fig. 1a the loci are formed with a range of time differences from minimum (zero) to maximum (hydrophone spacing / sound velocity in water) for two hydrophones only. Fig. 1b illustrates how the situation is compounded with three hydrophones and Fig. 1c illustrates the even more complex situation with four hydrophones. The intersection points are the possible positions of one or more echo-locating cetaceans.

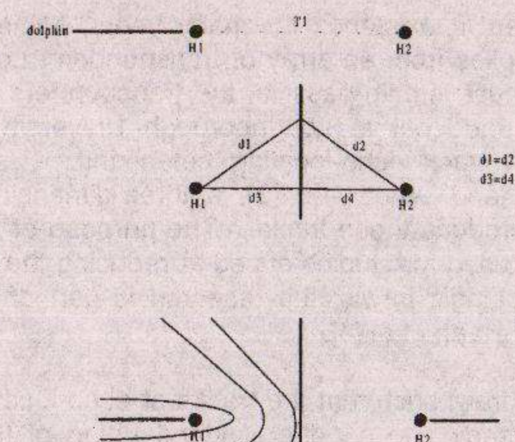

Fig. 1a, Two hydrophones.

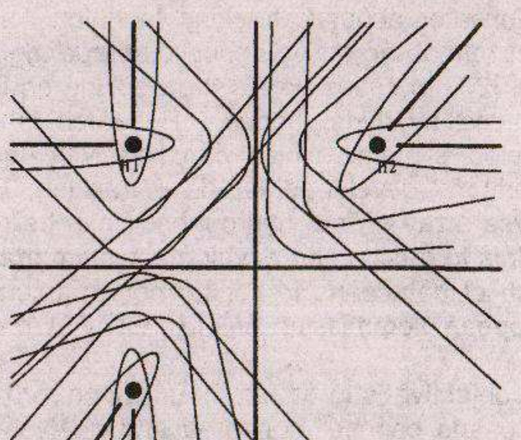

Fig. 1b, Three hydrophones.

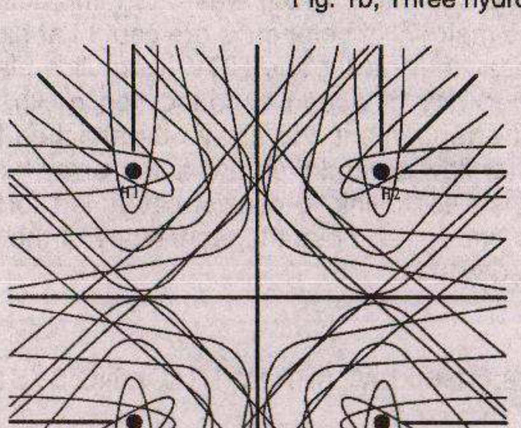

Fig. 1c, Four hydrophones.

In the three-dimensional case, the loci become the surfaces of a paraboloid, and the problem intensifies because the intersections of three-dimensional surfaces have to be calculated. Generally, a dual solution results, with mirror image positions on opposite sides of the plane of the array. This ambiguity can be removed by deploying a fifth hydrophone out of the plane of the other four. In practice, it is not necessary for this hydrophone to be as stable as those in the main array, where small movements can produce large errors. It is not straight forward to produce a general-case algorithm to calculate these points because the array may change its configuration with time. The array therefore needs to be recalibrated frequently because it could be in any of a range of configurations depending on the shape of the trawl. The project for which this system has been developed required the system at quite an early stage. A quick and simple solution therefore had to be found, so a *look-up* table solution was adopted whereby the area around the array is separated into descrete zones. For each zone a time differences is calculated for each pair of hydrophones. These are then sorted to reduce the time delay between data arrival and position calculation, allowing the system to work in near real-time. On the arrival of a click the timings are compared with the table and the corresponding position is plotted. The disadvantage of this method is the excess time needed to calibrate the array and create the look-up table. Using multi-tasking programming the effect of this calibration is minimised, thereby allowing tracking to continue even while re-calibrating.

3. THE SYSTEM HARDWARE

To produce a relatively stable array in a turbulent water flow required the use of two high technology hydrophone streamers and adjustments to the pelagic trawl to which they were attached. Each streamer consists of two hydrophones, with associated pre-amplifiers, and a calibration pinger. The information from the two streamers is sent to an underwater electronics unit which detects the cetacean echo-location clicks and extracts the arrival time information, which is sent via a 2 km co-axial cable to the ship. On board the ship the signals are stored on an instrumentation recorder and on a PC-based data-logger. This information is then sent to the tracking PC via an RS232 link, where the system is calibrated and the tracking algorithms are applied. The calibration system periodically pings from streamer to streamer, allowing the inter-hydrophone spacings to be calculated. If the array and fifth hydrophone are stable, the fifth hydrophone can be used as part of the array to increase the accuracy of the look-up table method.

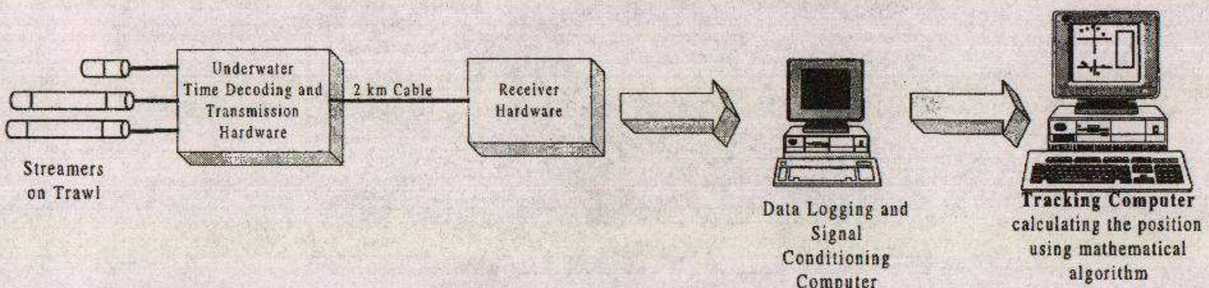

Fig. 2a The flat array tracking system.

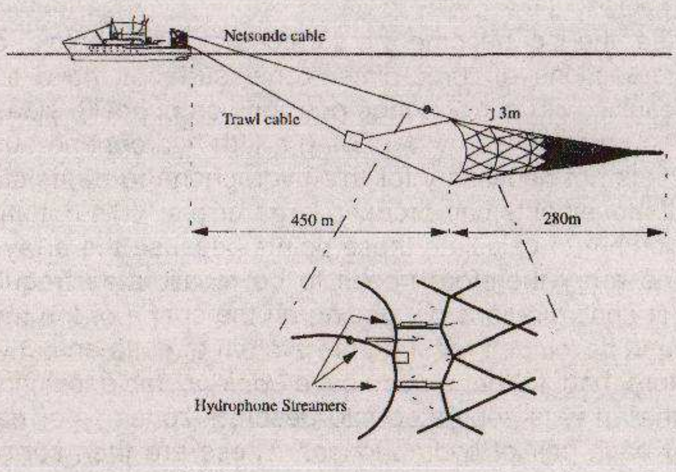

Fig. 2b Deployment of the array on the pelagic trawl

3. RESULTS

Two sets of streamers have been produced and tested. The accuracy of timing data from the arrays is limited by the transmission link, in this case a 2 km coaxial cable with a bandwidth capability of 100 kHz with pre-distortion, giving a maximum timing accuracy of 10 μs. This is a severe limitation for this type of position-fixing technique and results in the computation of several possible locations for each click. These locations tend to lie in a line from the source to the array, and means that source positions are defined in terms of vectors, rather than points. Multi-tasking software has been written using Borland Delphi 2 and Borland C++ Builder to produce the look-up table and update and re-sort it whenever a calibration pulse is detected. Any echo-location clicks detected by the system are plotted simultaneously on the screen, as shown in Fig. 3.

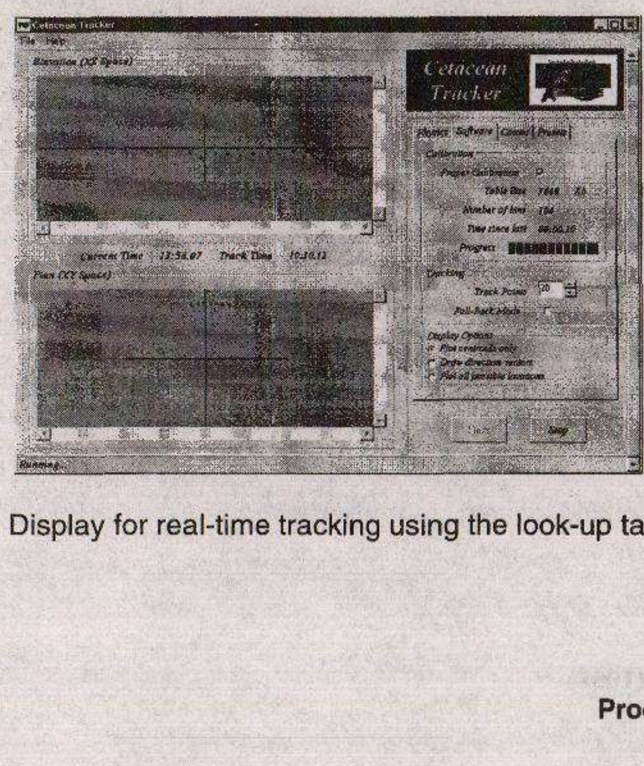

Fig. 3 Display for real-time tracking using the look-up table method.

The system has been fully deployed during two sea trials. Data is still being analysed, but the small numbers of cetaceans encountered has limited the testing of the system. Problems with the self-calibration system reduced the accuracy of the system, and these were exacerbated by the detection of click-like noise sources on the trawl itself, particularly the Netsonde headrope depth instrumentation.

5. CONCLUSIONS

A system for tracking echo-locating cetaceans in three-dimensional space in the vicinity of a moving trawl at sea has been described. The system has been used on several trials in the Atlantic and has yielded some preliminary results, although the constraints made by having to attach the hydrophone streamers to a working trawl and having to use bandwidth-limited coaxial cables for data transmission have severely limit the system's capability. In future work the transmission links will be changed to fibre optic cables, allowing higher data rates and therefore greater positional accuracy. The use of a fixed array in future will simplify the mathematical algorithms, allowing a mathematical approach to be used rather than the look-up table method.

6. ACKNOWLEDGEMENTS

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