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An Evaluation of a Continuous-Transmission, Frequency-Modulated Sonar in Fishery Research

Une evaluation du sonar a transmission continue et frequence modulee (CTFM) pour la recherche halieutique

Un sonar à transmission continue et fréquence modulée (CTFM) à été utilisé dans des études effectuées sur le listao (*Katsuwonus pelamis*) par le Laboratoire de biologie du Bureau des pêches commerciales des Etats-Unis à Honolulu, depuis 1966. Les capacités du sonar CTFM sont précisées, en ce qui concerne la portée, la définition et la vitesse d'information. On a attribué l'aisance avec laquelle les cibles sont détectées à sa transmission continue et à sa vitesse d'information élevée. A son début, l'emploi du sonar CTFM a entraîné des problèmes (1) de retards dans la réparation et le réglage provenant d'un personnel inexpérimenté et d'un manque de pièces, et (2) de conversion analogique-digitale de données enregistrées à un rythme très rapide. Le sonar CTFM a été utilisé pour rechercher et suivre le listao. Pendant les opérations de poursuite, des difficultés ont été provoquées par des déplacements brusques et imprévisibles, une faible propriété réfléchissante du son et une tendance de ces poissons à faire des émulsions d'air dans l'eau en surface. Un petit émetteur placé dans un poisson a permis de réussir des opérations de poursuite. Les problèmes englobant les rythmes de détection et l'identification de l'écho pendant les opérations de recherche sont discutés. On résume les informations obtenues sur le comportement du listao grâce à l'emploi du sonar. L'utilisation des sonars CTFM dans l'industrie des pêches est discutée.

Evaluación del sonar de CTFM en la investigación pesquera

En el Laboratorio de Biología que la Oficina de Pesca Comercial de los E.U.A. tiene en Honolulú, se emplea desde 1966 un sonar de transmisión continua y frecuencia modulada (CTFM) en el estudio del listado, *Katsuwonus pelamis*. Se decriben las posibilidades de este aparato en lo relativo al alcance, resolución y velocidad a que suministra la información. La facilidad con que se localizaron los objectivos se atribuyó a su transmisión continua y a la gran rapides con que facilita los datos. Los problemas relacionados con el uso inicial del sonar CTFM fueron: (1) retrasos en las reparaciones y ajustes debidos a la inexperencia del personal y a no disponerse de piezas y (2) convertir a gran velocidad los datos registrados de digital a análogos. El sonar de CTFM se empleó para buscar y seguir el listado. Durante la persecución crearon dificultades sus movimientos repentinos e imprevisibles, lo mal que reflejan los sonidos y su tendencia a crear burbujas de aire mientras están en la superficie. Dio buenos resultados un pequeño transmisor ultrasónico que se había puesto en los ejemplares que se iban a seguir. Se examinan los problemas que plantea la velocidad de localización e identificación de los objetivos durante la búsqueda. Se presenta resumida la información sobre el comportamiento del listado obtenida empleando el sonar. Se discute el empleo de sonar CTFM por la industria pesquera.

IN the last decade two interesting developments in underwater acoustic equipment have been applied towards fishery problems. Both of these, the sector-scanning sonar and the continuous-transmission, frequency-modulated (CTFM) sonar, represent departures from conventional pulsed sound techniques to provide high resolution and high rates of information. Although they are quite different from each other, both use narrow beams and rapid scanning to accomplish their objectives. The sector-scanning sonar scans bearing as its first order of scanning while the CTFM sonar scans range as its first order of scanning. Their potential as demonstrated by initial trials and applications in fishery research (Harden Jones and McCartney, 1962; Tucker and Welsby, 1964; Cushing and Harden Jones, 1966; Hester, 1967; and Yuen, 1968) has attracted considerable interest.

A CTFM sonar was purchased by the Bureau of Commercial Fisheries Biological Laboratory, Honolulu, in 1966 to further its studies on tuna behaviour and distribution. The CTFM sonar was chosen over conventional sonars because we believed that the conventional sonars would be inadequate for keeping in contact with the quick moving tunas. The project involving the CTFM sonar set out to do the following: describe the short-term movements, both horizontal and vertical, of the skipjack tuna, *Katsuwonus pelamis*, and investigate the relation between the movements and environmental features; measure such schooling parameters as school size, density, configuration, and stability; describe the migration route of skipjack tuna; and evaluate the effectiveness of the CTFM sonar in locating subsurface tunas.

This evaluation of the CTFM sonar is based on my working experience with it since 1966 and is presented largely from a non-technical viewpoint. The report includes the capabilities and limitations of the CTFM sonar, problems encountered in its use, corrective measures, results of current work and a discussion of its potential use in the fishing industry.

CAPABILITIES AND LIMITATIONS

The distance an object can be detected by sonar depends on how well the object reflects the sonar signals. The CTFM sonar has a range of 1600 m for objects with echoes of sufficient strength. The detection ranges of various species (Table I) are reproduced from Yuen, 1967.

TABLE I. MAXIMUM RANGES AT WHICH VARIOUS ANIMAL TARGETS WERE OBSERVED ON THE CRT DISPLAY

Mode	*Target*	*Maximum range (m)*
Search	Dead skipjack tuna (65 to 75 cm fork length)	
	One	235
	Two (one above other, 30 cm apart)	340
	Three (one above other, 35 cm apart)	380
	Surface skipjack tuna schools (1 to 11 kg)[1]	650
	School of yellowfin tuna (*Thunnus albacares*) (18 kg)[1]	545
	Subsurface fish (unidentified)	389
	Whitetip shark (*Carcharhinus longimanus*)[1]	340
	Billfish (Istiophoridae)[1]	280
	Porpoise[2] (probably *Stenella attenuata* or *Steno bredanensis*)	
	One	ca. 400
	Group	800
Classify	Dead skipjack tuna (65 to 75 cm fork length)	
	One	130
	Two (one above other, 30 cm apart)	130
	Three (one above other, 35 cm apart)	130

[1] Identified visually at the sea surface.
[2] Identified from the display of their own sounds on the CRT.

Although skipjack tuna were detected up to 650 m, the limit of detection for this species was usually 300 to 400 m.

The CTFM sonar has a high resolution mode called the classify mode. In this mode the sonar has a range resolution of 0.0019 times the target distance and a bearing resolution of 0.01 times the target distance. This means that if there are two targets one behind the other relative to the sonar transducer at a distance of 100 m, they would need to be at least 19 cm apart to be recognizable as two targets. If the two fish were at different bearings but at the same range they would need to be 1 m apart at a distance of 100 m to be distinguishable as two targets.

The sonar can be operated at a ship's speed of 18 km/h (10 kn). Beyond 11 km/h (6 kn), however, noise level begins to interfere with effective operations. At 15 km/h (8 kn) virtually no useful information can be obtained.

The outstanding feature of the CTFM sonar is its continuous transmission of acoustic energy. As illustrated in fig 1, the projected signal is frequency modulated in a sawtooth pattern. Subtracting the frequency of the outgoing signal from that of the echo results in a difference

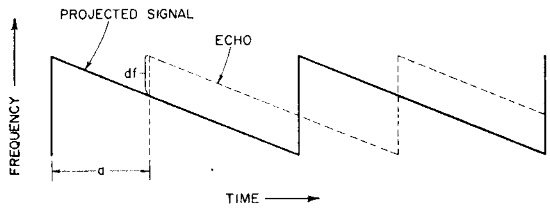

Fig 1. Pattern of frequency modulated signal and echo. a = loss time, df = difference frequency

frequency labelled *df* in fig 1. The magnitude of the difference frequency is proportional to the time lapse between the transmission and the return of the echo. The time lapse, labelled *a* in fig 1, is in turn proportional to the distance of the reflecting object so that the difference frequency is also proportional to this distance. Information on the target is received throughout the sawtooth period after the time lapse *a*. In a conventional pulsed sonar the information is only available for the length of the pulse.

Since no information is received during the time lapse *a*, this period is called the *loss time*. There is a method to recover the information during the loss time but it is not incorporated in our sonar.

Loss time increases as target distance increases so that the length of time that information is received varies inversely with target distance. Information time can be lengthened proportionately by lengthening the period of the sawtooth. The gain in information time by this method, however, is made at the expense of range resolution.

The difference frequency is processed through a frequency analyzer of 100 bandpass filters. The outputs of the filters are read sequentially every 7 msec. The 7 msec. can be divided into a reading time of 5 msec. and a pause of 2 msec. A high information rate is the result of this rapid reading rate.

How do the attributes of continuous transmission and high information rate contribute to the performance of the sonar in locating a target? The question can best be answered by reviewing an experiment. A target was placed in the water. Its depth was changed at various times from 10 m to 80 m below the surface. The ship repeatedly went past the target at various distances at a speed of 7.5 km/h (4 kn). The sonar operators were instructed to find the target with no prior knowledge about its position. Furthermore, the operations of the sonar was restricted to a standard scanning pattern for searching. The target was detected 23 out of the 24 times the ship passed within sonar range of the target. In my opinion, the high detection rate was possible only because of the features of rapid information and continuous transmission of the sonar.

The high certainty of detecting objects has provided an unexpected benefit. The sonar has been used successfully in locating submerged instruments which had lost their surface markers.

PROBLEMS

Some problems were encountered in the use of the CTFM sonar. Some were solved; others corrected themselves with time; others still remain. Corrective measures taken are described.

One early problem was the time spent on repairs and adjustments. Because the equipment was new, maintenance personnel were unfamiliar with it. As a result repairs and adjustments, even minor ones, required much time. As personnel gained experience, the seriousness of the problem diminished.

The sonar has many specialized components whose replacements are difficult to obtain. Some parts are not available in Hawaii. Others are constructed as they are ordered; these are not readily available anywhere. Delays of various durations have resulted when parts were not on hand. In the most extreme case a high precision potentiometer required 18 months to obtain. During that time the classify mode was out of order. Delays in repairs have been considerably reduced but not entirely eliminated by storing an extensive supply of spare parts, particularly critical ones.

The data collected during sonar operations were recorded on a 14-channel, analog, magnetic tape recorder. To make the data acceptable for processing by a computer, conversion from analog to digital was necessary. A problem was encountered in digitizing of the sets of the 100 sequential readings of the frequency analyzer. It was necessary to signal the analog-to-digital converter to start precisely at the beginning of each set. Failure to do so would have caused the sets to become mixed, which would have rendered the data meaningless. Efforts at instructing the computer directing the conversions to detect the exact starting time and then to signal the converter failed because there was insufficient time between the detection process and the signalling process. Conversions were successfully made when an electronic device was added to the system to suppress signals activating the converter unless they began at the same time as the sets of reading from the frequency analyzer.

The operations of the CTFM sonar were of two types. It was used primarily to track skipjack tuna which had been located and identified visually. Tracking operations were for the purpose of obtaining behaviour observations. The sonar was used secondarily to find subsurface schools of skipjack tuna. Searching and tracking operations were both hampered by the limited range at which skipjack could be detected. Within the area of the Hawaiian skipjack tuna fishery, where most of the work with the sonar has been done, surface schools of this species have been sighted at a rate of approximately one per 300 km^2. Even if one supposes that for every school at the surface there is another beneath the surface, a sonar scanning a radius of 400 m on a ship travelling at 10 km/h would have an expected detection rate of one school per 10 hours. This result is based on the assumption that the skipjack schools move randomly at a speed of 5 km/h.

The effective range of 300 to 400 m for skipjack tuna was found to be inadequate during tracking operations. The fish with their sudden and unpredictable movements moved out of range before the ship could be manoeuvred in response.

A difficult problem in searching with a sonar is target identification. At present the more experienced sonar operators believe that they can identify echoes of skipjack tuna and sharks. The identification criteria, however, are subjective and therefore difficult to describe. An attempt is being made to formulate objective criteria of identification. To do this, sonar records of positively identified species will be processed through a computer for analyses of strength, movement, and spacing of echoes with respect to time. Since the information from the sonar has been recorded in cycles of 7 msec, very detailed analyses will result in a practical method of identifying species.

Skipjack tuna at the surface presented special problems which made tracking them difficult. The strength of echoes of skipjack tuna, as with most fishes, depends upon the orientation of the fish to the sonar. Echoes are strongest with a lateral aspect of the fish and weakest with the head and tail aspects. Dorsal and ventral aspects result in echoes which are almost as strong as those from a lateral aspect. Echoes from fish below the sonar, therefore, are consistently fairly strong because the fish present a dorsal aspect regardless of the direction they are swimming. Echoes from surface fish, on the other hand, vary widely in strength as the fish change their directions. Furthermore, when one is tracking a fish one is likely, most of the time, to be behind the fish, where the echoes are the weakest.

Another problem with skipjack tuna at the surface is that they have a tendency to break through the surface and thus introduce masses of air bubbles into the water. Unwary sonar operators have often concentrated on the echoes from these air bubbles while the fish moved away. A tracking technique with some degree of success was to have the operator constantly scan below the fish in order to detect them when they left the surface. Of course, the procedure did not work if the fish moved out of range before leaving the surface.

In the summer of 1969 a major advance in tracking was made. A skipjack tuna that had been induced to swallow a small 50 kHz transmitter was followed with the sonar for six days; another for 12 hours. The transmitters could be detected up to 2.5 km. The transmitters which were used had a life of 10 days but transmitters lasting 60 days are now available.

RESULTS AND COMMENTS

The CTFM sonar has been used by the Biological Laboratory, Honolulu, primarily as a tracking device to study the behaviour of skipjack tuna. Results thus far indicate that: (1) skipjack tuna will go as deep as 200 m; (2) larger skipjack tuna tend to go deeper than smaller ones; (3) small skipjack tuna remain close to the surface at night but make many excursions away from the surface during the day; (4) the speeds of their vertical movements average 0.3 m/s and can be as high as 3.3 m/s.

Behaviour information of the type mentioned is useful in the design of fishing gear and strategy and thus contributes to the fishing industry from a long-range point of view. When a fisherman considers installing a sonar on his boat, however, he is interested in obtaining information for immediate use. Moreover, he is primarily interested in an inexpensive method of efficiently locating fish. Other information is of secondary importance. For the CTFM sonar to be widely accepted in the fishing industry, therefore, it must be inexpensive and its effectiveness as a fish finder needs to be demonstrated.

The sonar model here discussed costs US $210,000. It is much more complex than would be required for fish finding purposes.

The low detection rate for skipjack tuna in the Hawaiian fishery does not mean the CTFM sonar will not be useful as a fish finder in other fisheries. The detection rate for a given species depends on species-related parameters. In most cases, the rate can be expected to be higher than that for skipjack tuna. Because of the importance of the swim bladder in reflecting acoustic energy (Cushing and Richardson, 1955; and Harden Jones and Pearce, 1958) echoes from skipjack tuna, which do not have swim bladders, are weaker than those from many species which do have swim bladders. Species which are more concentrated in their distribution than the apparently widely separated schools of skipjack tuna will have a higher detection rate. The probability of detection increases with an increase in the difference between the swimming speed of the fish and the searching speed of the ship. In general, slower swimming fish will be more likely to be encountered than faster swimming fish such as the skipjack tuna. Whether detection rates will be high enough to justify the cost of a CTFM sonar will have to be determined individually for each fishery.

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