IDENTIFICATION MECHANISMS OF TARGET VELOCITY CHARACTERISTICS BY DOLPHINS (*TURSIOPS TRUNCATUS*) AND TECHNICAL DEVICES FOR HYDRO-LOCATION AND RADIO-LOCATION

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1. ABSTRACT

The capacity of a bottlenose dolphin (Tursiops truncatus) to discriminate between the dynamic characteristics of a target moving radially has been studied. The dolphin's sensitivity thresholds for determining target velocity (2.6 cm/s) and target acceleration (0.6 cm/s^2) were also studied. It was shown that an animal emits a two-pulse probe signal to locate a target moving with constant velocity, or a three-pulse probe signal to locate an accelerating target. New highly efficient technical methods of hydro-location and radio-location are suggested on the basis of these observations and measurements.

Key words: dolphin, target's velocity characteristics, hydro-location, radio-location.

2. INTRODUCTION

It is well known that marine animals, while performing active hydro-location, are capable of distinguishing non-moving targets from the moving targets, not only at high speed but at very low speed, when the targets are not themselves sources of sound [1]. But only a few papers have been devoted to the capability of a dolphin’s sonar to identify and recognise moving targets [2-4].

In the present work, the sensitivity of dolphin sonar systems to moving targets has been investigated. This has involved looking at the probability of detection for targets moving with different velocity and acceleration, and the method of echolocation for such dynamic targets. As a result of fundamental physiological research, a new highly effective technique of hydro-location and radio-location is presented.

3. METHODS

Techniques of dolphin conditional reflex training have been developed to distinguish moving (search) targets from identical non-moving (background) targets and then to distinguish accelerating (search) target from a uniformly moving (background) target. The correct spatial choice of a search target by a dolphin was encouraged by providing it with food (fish). Target displacement was carried out along a radial trajectory with respect to the dolphin, the target either coming nearer to or going farther away from the dolphin. Measurements were made using a special installation with electronic control to move the targets. Investigations were carried out in a pile-net enclosure in an open-sea bay in the absence of rough water and external noise.

4. RESULTS AND DISCUSSION

100% efficiency of moving target identification was achieved by a trained dolphin when the velocity of the target was more than 3.2 cm/s. At velocities up to 2.6 cm/s the efficiency of search target identification decreased to 75% (the velocity sensitivity threshold to a search target). If the acceleration of a search target was increased from 0.12 to 0.84 cm/s the efficiency of its identification by the dolphin grew steadily, up from 5-10% to 95-100%, reaching 75% at the acceleration of 0.6 cm/s^2, the sensitivity threshold.

The assumption is made [5] that a dolphin possesses Doppler discrimination for the perception and estimation of movement, as in the case with bats, although we think this to be improbable. The experimentally measured values of threshold signal frequency discrimination by a dolphin, in a working range from 0.9 to 90 kHz, appeared to be much higher than the value of the shift estimated for the same frequencies, especially at small and moderate velocities to the target approach [6]. It means that the Doppler shift of the sonar frequency in its specified range is much less than the threshold of a dolphin's sensitivity to differential frequencies and, consequently, is not perceived.

Dolphins are easily capable of identifying a target's movement over a very wide range of velocities, from high (~50 km/h) to very low (~2.6 cm/s). But how the dolphins achieve this was not clear until our research was completed.

We have found that a dolphin, when locating targets moving with constant velocity, uses certain probing signals that are different from those used for the location of accelerating targets (Figure 1).

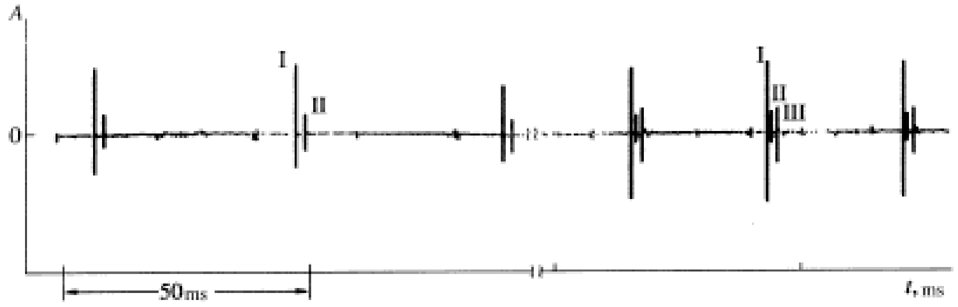

Fig. 1. Structure of a dolphin's echo-location signal: two-pulse signal while detecting a target moving with constant velocity (left) and three-pulse signal while detecting target acceleration (right).

When detecting a target moving with constant velocity, a dolphin was found to emit probing "packets" of signals, each consisting of two short high-frequency pulses I and II. The time interval between these pulses was 1.8 ms, which did not change during the experiments. The amplitude of pulse II was found to be less than that of pulse I and typically 0.3-0.4 of the amplitude of pulse I.

For an accelerating target, the dolphin was found to emit other probing "packets" of signals, each consisting not of two, but of three consecutive short high-frequency pulses I, II and III. The total duration of the packet was also about 1.8 ms, therefore similar to that of the two-pulse "packet". The interval between pulse I and pulse II, which had the lowest amplitude of the three, was 0.5-0.8 ms, while the interval between pulse II and pulse III was 1.0-1.3 ms.

We have come to the conclusion that a dolphin is capable of emitting double signals to determine the velocity of a target and treble signals to determine the acceleration. The results were unexpected and surprising, for nobody has previously observed this behavior. The question arose as to whether it is possible to validate this identification of velocity and acceleration. We succeeded in finding a solution to the problem and we offer a new technical method below.

The solution is presented in Figure 2, which shows a timing diagram of the emission and reception of a “packet” of three rectangular pulses C_1, C_2 and C_3. The technique proposed is realised as follows.

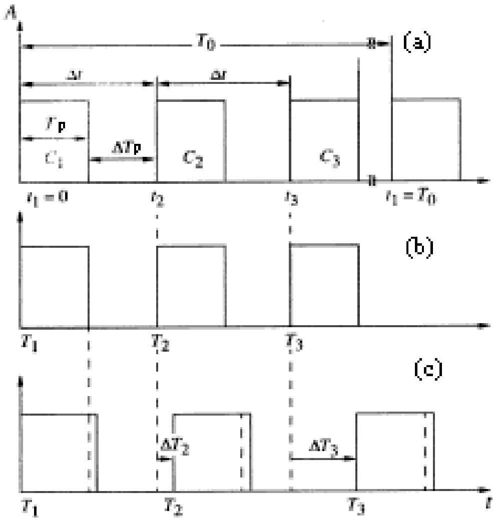

Fig. 2. Timing diagram of emission and reception of a probing “packet” of three rectangular pulses by an active control system (hydro-locator, radar or other). a) emission of a "packet" of pulses C_1, C_2, C_3, where T_0 – packet period, T_p – pulse duration, ΔT_p – a pause of a pulse, Δt – pulse period; b) reception of reflected pulses C_1, C_2, C_3 from a motionless object, where T_1, T_2, T_3 – moments of detection reflected pulses C_1, C_2, C_3; c) reception of reflected pulses C_1, C_2, C_3 from a target in the active control system.

The source emits a “packet” of pulses of the set repetition rate, for example, three consecutive signals (C_1, C_2, C_3) with period Δt, duration T_p and pulse intervals ΔT_p (Figure 2a). If the distance to the target does not change (i.e. the target is motionless) the first signal C_1 of a packet returns to the receiver after reflection from the target in a certain time T_1, the second C_2 in time $T_2=T_1+\Delta t$, the third C_3 in time $T_3=T_1+2\Delta t$. Thus, all three signals travel the same path $2S_1$, where S_1 is the range to the target. The coincidence of experimental values T_2 (or T_3) shows that the range to the target from the moment of target interception by signal C_1 to the moment of interception by signal C_2 (or C_3) does not changed. The range S_1 can be found from: $2S_1=vT_1$. If the range changes, C_1 reaches the target at range S_1, while C_2 reaches it at range $S_2=S1+S_{1,2}$, and C_3 at range $S_3=S_1+S_{1,3}$. Thus C_1 will return to the receiver after reflection from the target in time T_1, C_2 in time $T_2=T_1+\ \Delta t+\Delta T_2$, and C_3 in time $T_3=T_1+2\Delta t+\Delta T_3$. The path length of C_2 differs from that of C_1 by $S_{1,2}=V_{1,2}t_{1,2}-V_{1,2}0.5\Delta T_2$, where $V_{1,2}$ is the relative average radial velocity of the target and $t_{1,2}$ is the time between target contact for C_1 and C_2. Similarly, the path length of C_3 differs from that of C_2 by $S_{2,3}=V_{2,3}t_{2,3=}V_{2,3}0,5(\Delta T_3-\Delta T_2)$, where $V_{2,3}$ is relative average radial velocity of the target and $t_{2,3}$ is the time between the target contact for C_2 and C_3. Then $S_1=VT_1$; $S_2=V(T_2+\Delta T_2-\Delta t)$; $S_3=V(T_3+\Delta T_3-$

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$2\Delta t)$; $S_{1,2}=S_2-S_1$; $S_{2,3}=S_3-S_2$; $V_{1,2}=2S_{1,2}/\Delta T_2$; $V_{2,3}=2S_{2,3}/\Delta T_3-\Delta T_2$; and $a_{1,3}=2(V_{2,3}-V_{1,2})/t_{1,3}$, where $a_{1,3}$ is average radial acceleration of the target relative between target contact with C_1 and C_3.

The discovery allows us to considerably expand functional opportunities of hydro-location and radio-location methods, to increase the number of parameters determined, and to increase the speed and accuracy of their definition in comparison with other known methods.

In particular, when sending a packet of three consecutive signals, the distance to a target is measured three times instead of once, while the velocity of any relative movement is measured twice and the relative acceleration only once. Simultaneously, the determination of the distance to the target, and its radial velocity and acceleration, enables us quickly to generate corresponding command signals for the regulation of the target's location and movement.

It has also been shown that the method used by a dolphin to determine relative velocity and acceleration of target, including sending a probing packet of several pulses, can be used in other applications. For example, a radar emits pulses packets, not consistently one after another, but simultaneously. The pulses should have different distribution velocities in probing the environment. The location of ships can be achieved by the simultaneous radiation of two pulses with different velocities, one above the water, the other under the water, where the velocity of sound distribution is five times higher, than in the air.

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