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REAL TIME CLICK INTERVAL ACQUISITION SYSTEM FOR DOLPHIN ECHOLOCATION SIGNALS

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1. INTRODUCTION

Click intervals of trained dolphins are known to be longer than the target range, for example, bottlenose dolphins [1,2] and a false killer whale [3]. Penner [2], reported the click intervals of bottlenose dolphins were much longer at a target absent task than a target existed task. Thomas and Turl [3], suggested that the false killer whale may have searched for a target at several locations along the range, since miss or false alarm trials had more variable inter click intervals. Dolphins seemed to change their echolocation range depending on the sensory demands.

On the other hand, echolocation range of free-ranging dolphins and porpoises are not well known, mainly due to the difficulty of high frequency underwater sounds recording in open waters. Click intervals of free-ranging dolphins and porpoises are thought to provide their echolocation range in the wild. Using high frequency adapted digital data recorder and a hydrophone, real time click interval and sound pressure level acquisition system were developed.

2. MATERIALS

High frequency adapted hydrophone (B&K 8103, up to 180 kHz, -211dB re 1V/micro Pa or OKI ST8004, up to 200 kHz, -220dB re 1V/μ Pa) and a digital data recorder (SONY PCHB 244, sampling rate was 384 kHz) were used for the acoustic observation of dolphins in the wild and in a tank. Frequency response of the data recorder was good for up to 147 kHz (-2dB). Most of the frequency components of clicks are limited up to 150 kHz, reviewed by Au [4] and Richardson et al. [5]. Consequently, the total frequency response of the sound recording systems were enough to observe the clicks of dolphins.

Clicks are composed of high frequency pulse series. The duration of a click are 40 microseconds to 600 microseconds [4] and the click intervals are highly variable, ranged from a few milliseconds [6] to 150 milliseconds [7] or 250 milliseconds [3]. The data acquisition system must have enough facility to process such high repetition rate pulse series for the real time data analysis. We can not know when a dolphin produce clicks, thus the analogue digital conversion, data comparison and saving to a data file have to be completed before the next detection of a click. Additionally, the time resolution have to be smaller than the minimum click intervals.

A signal processing circuit (Click Detector) and a 486 MPU (66 MHz) based personal computer with an analogue digital converter (Micro Science ADM-652AT) and a data acquisition program on Windows 95 © were developed for real time analysis of clicks. Signal processing of the data acquisition system was illustrated in Figure 1.

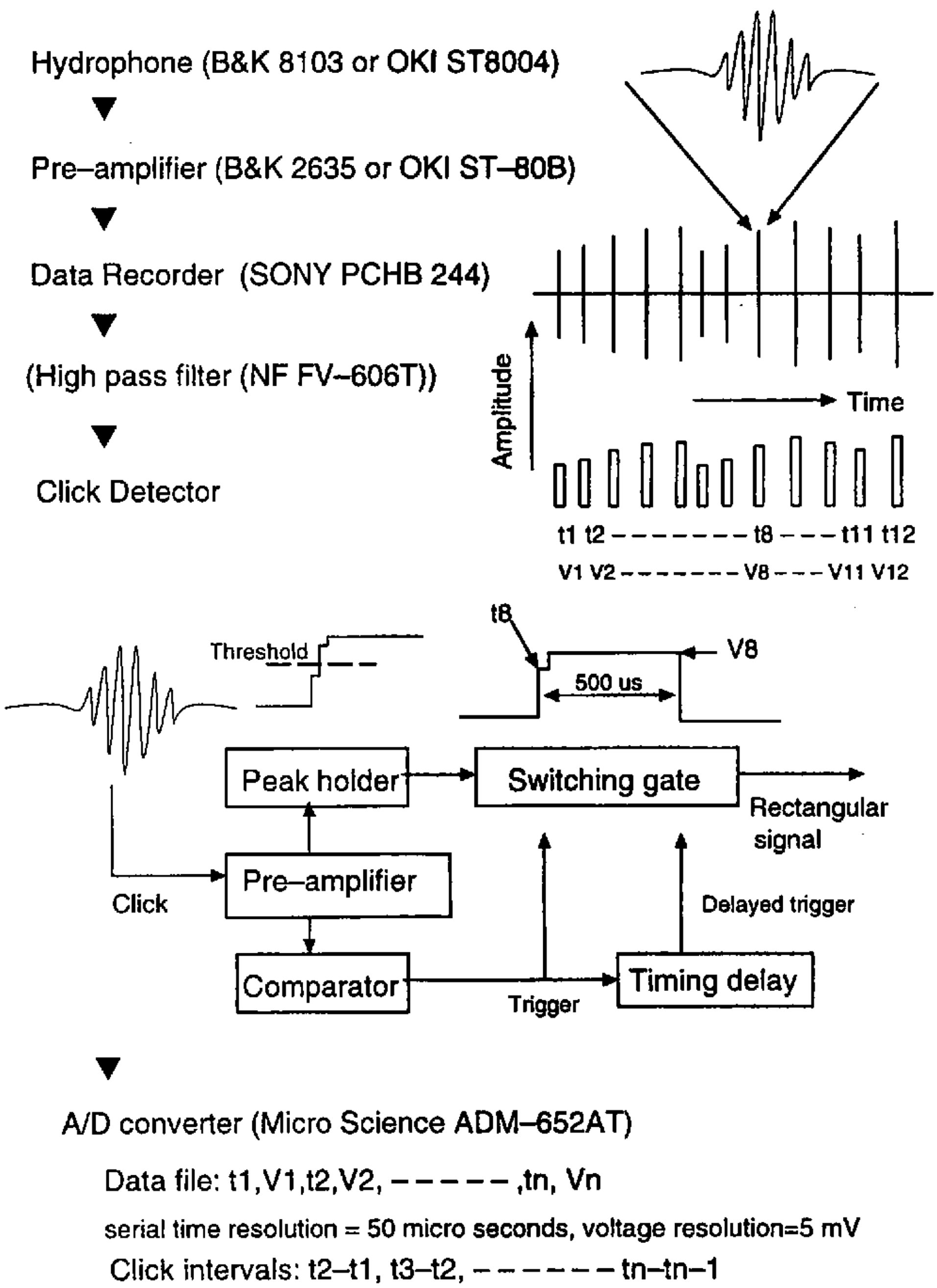


Figure 1. Sound recording and data acquisition systems

Click Detector converted a click to a 500 microseconds duration rectangular signal whose voltage level was in proportion to the peak level of the click. The signal processing was as follows. The peak level of a click was fixed, and a comparator generated a trigger signal when the voltage level was larger than the threshold level. The threshold level could be changed from 100 mV to 500 mV to eliminate the false activation of Click Detector by background noises and reverberated signals. The trigger signal and a delayed one were fed to a switching gate to produce rectangular signal whose amplitude was in proportion to the peak level of the click. At the analysis of the bottlenose dolphin clicks, 20 kHz high pass filter (NF FV-606T) was connected before Click Detector to eliminate the false activation by whistles.

In the present study, high frequency adapted data recorder was used to observe clicks of dolphins. However, the output signals of Click Detector can be recorded by a band-limited equipment. Using Click Detector between a hydrophone and a commercial recorder like a potable DAT, the interval and the amplitude information of clicks will be obtained. Click Detector is small (14 cm in length, 10 cm in width and 4.5 cm in height) and easy to operate, since only two BNC connectors for high frequency inputs and rectangular outputs are prepared. It runs four hours long by dry batteries and costs less than $800. The detection of clicks indicated by an LED flushing in front of the device. Click Detector is suitable for acoustical observations of dolphin clicks on a small boat in an open waters.

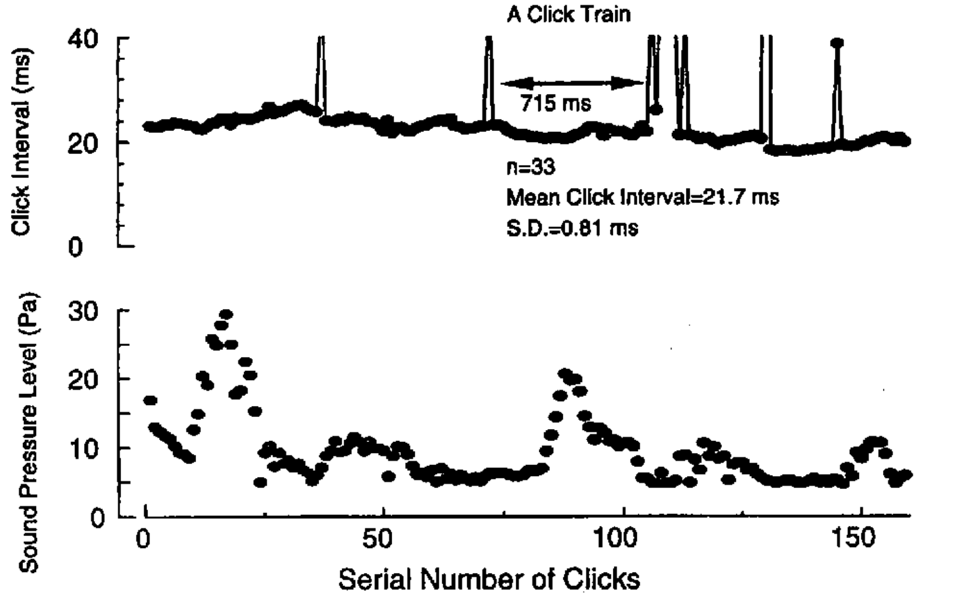
The analogue digital converter was operated 20 kHz sampling rate by a data acquisition program. Serial time and output voltage level of the rectangular signal were obtained every 50 microseconds. Voltage levels (+/- 10V range) was converted to 12 bit binary code. Thus the voltage resolution was 5 mV. A physical detection threshold level of a whole system was 127 dB re 1μPa (rms) at the 100 mV threshold of Click Detector and at 316 mV/ unit out range of B&K 2635 which was a charge amplifier of the hydrophone B&K 8103. The maximum voltage level and the initial sampled time in the rectangular signal were saved on a random access memory of the personal computer (Figure 1). This algorithm avoided a lower voltage level at an onset of a click. Consequently, time and sound pressure resolution were 50 microseconds and 0.1 Pa respectively. The data processing was enough fast to save all of the dolphin's clicks.

3. APPLICATION

An example of click intervals (ms) and sound pressure levels (Pa) obtained from a captive baiji (*Lipotes vexillifer*) were illustrated in Figure 2. Click intervals changed smoothly in a click train. Typical changes of sound pressure level in a click train have a 'mountain' shape which show gradual increment and gradual decrement of sound pressure levels as shown in lower picture of Figure 2.

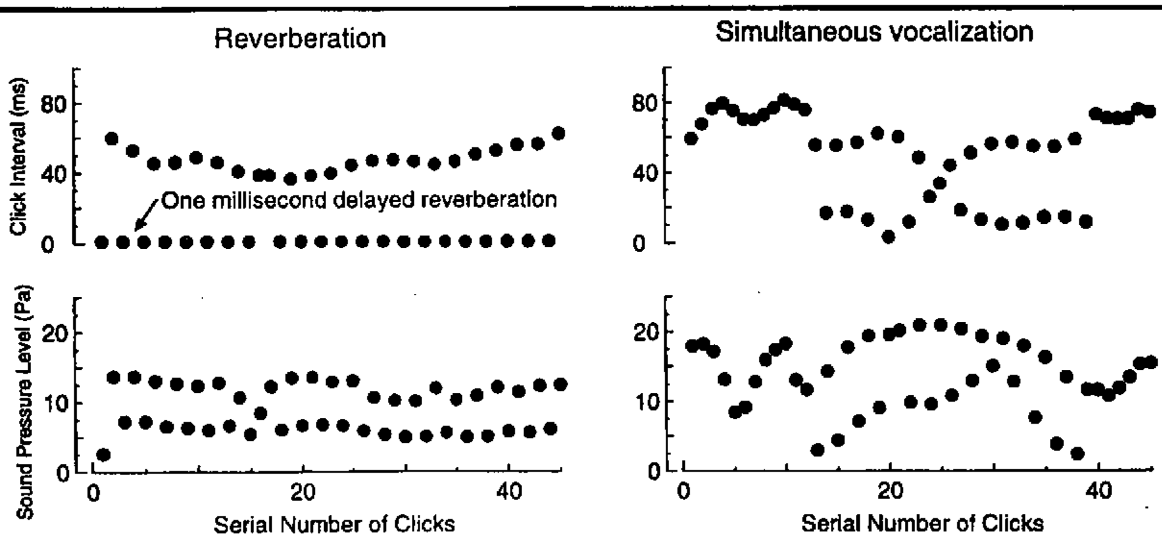
In contrast, reverberated signals from a water surface, a bottom or a tank wall shows alternative change of click intervals and sound pressure levels (Figure 3; left). The reverberated signals were mostly recorded within one or two milliseconds after the former signals in a tank. Changes of sound pressure level of the reverberated signals closely associated with former signals.

Simultaneous vocalization by two or more individuals also exhibit irregular change of click intervals and sound pressure levels (Figure 3; right). Two independent change of the sound pressure levels were obtained from wild bottlenose dolphins (*Tursiops truncatus*) around Mikura Island in Japan. In



Baiji in a tank

Figure 2. Typical changes of click intervals and sound pressure levels of a captive baiji



Baiji in a tank

Bottlenose dolphin in an open ocean

Figure 3. Reverberated signals of a captive baiji and simultaneous vocalization of two bottlenose dolphins.

this case, actual click intervals of an individual were not depicted, because the actual interval was divided by a click produced by another dolphin. The dividing point in an actual click interval changed click by click due to the incommensurate change of click intervals of two dolphins. Consequently, symmetric changes of intervals (crossing lines in upper picture of Figure 3; right) were recorded. These click interval and sound pressure level patterns were clearly distinctive from the regular click trains as shown in Figure 2.

The high frequency adapted sound recording system and the data acquisition systems of the present study had already been applied for several dolphin species (baiji, finless porpoise, harbour porpoise and bottlenose dolphin). Click intervals of free-ranging dolphins seemed to be correlated with the environmental size and behavioral contexts. These subjects will be discussed in the future research.

4. ACKNOWLEDGEMENTS

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