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AN EXPERIMENTAL ACOUSTIC TEMPORAL CORRELATION LOG FOR SHIP NAVIGATION

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ABSTRACT

Acoustic Doppler logs have generally replaced traditional speed logs on board merchant ships, but their operation is far from ideal. Consequently, increasing interest has been shown in the acoustic correlation log which promises to overcome some of the deficiencies of the Doppler log. Advantages of it include bottom tracking the velocity to a greater depth than a Doppler log and much simpler transmitting and receiving array design.

The transducer arrangement is similar to the conventional echo sounder, where the pulses are transmitted vertically downwards. It is possible to operate the log in pulsed mode to great depths.

In shallow water a CW mode can be engaged, which permits a correlation log to be implemented easily at low cost and is ideal for navigation in shallow coastal waters, rivers and estuaries. It is this mode which is primarily under investigation and the subject of this paper. The paper describes work undertaken at LUT in implementing a CW correlation log in a water tank for the velocity measurement of a tracked platform.

INTRODUCTION

This paper describes work undertaken in the design and development of a temporal correlation log for the measurement of a ship's velocity. Initial experiments were carried out in a laboratory tank by measuring the velocity of a tracked platform. The platform runs in a straight line, horizontally across one side of the tank on two tracked girders approximately 300 mm above the water surface. Two stepper motors provide the motive force to drive it under computer control; this gives it a precisely known velocity.

The equipment is comprised of three parts, a projector/hydrophone array, a rack-mounted sonar and a microcomputer for control, which is interfaced to it as shown in Figure 1. The projector/hydrophone array is attached to the platform so that its propagation axis is in line with the tank's length and so that echoes are received from the end wall. This allows echoes to be received from the far field of the array at an effective range of approximately 8m (the tank's length). The transducers, with a 23^{o} half power beamwidth, are operated at their resonant frequency of 218 kHz.

The sonar rack houses all the electronics for the processing of the sonar signals, namely a transmitter, a dual-channel amplitude demodulating receiver and a digitiser. The transmitter is comprised of a stable reference oscillator feeding an external power amplifier via an attenuator which sets the transmitted continuous wave power level. The amplifier drives the projector located on the submerged transmitting/receiving array. The received echoes are picked up by the two hydrophones and are fed to the dual-channel receiver where they are amplified and detected. The two output voltage levels corresponding to the amplitude of the received signals are then digitised and passed to a microcomputer for processing.

A control program written in PASCAL configures the system as required. Parameters can be changed by choosing options from a Menu-driven user interface. Digitised samples can be stored on disc for later analysis, so that a comparison between different signal processing algorithms can be made.

THEORY

The temporal correlation log relies on the time delay measurement between signals received from two hydrophones H1 and H2 travelling inline with the velocity vector $\underline{V}$ of interest. If the hydrophone vector separation is $\underline{d}$ and the time delay measurement is T, then velocity vector $\underline{V}$ is given by

$$\underline{V} = \underline{d}/2T$$

as explained below.

In order to measure the time delay both received signals should be identical for perfect correlation; this is known as waveform invariance and is the basis of correlation velocity measurement. De-correlation occurs when the two signals are not identical, but a time delay measurement is still possible.

Dickey[1] described an aircraft navigator based on a continuous wave correlation radar. In the present work his explanation for identical signal reception is applied to a sonar system, shown in Figure 2, comprising two identical hydrophones H1 and H2 separated by a distance vector $\underline{d}$, and a projector P located midway between them. On a ship both the hydrophones and projector point vertically downwards. They move forward with a velocity $\underline{V}$, and the projector transmits a cw signal. Let the received signals on H1 and H2 be r1(t) and r2(t) respectively, and their detected envelope from the receivers be R1(t) and R2(t). Consider a point scatterer S at time t1, lying in a position where it intercepts the transmitted beam. Then the path length of the ray from P to the scatterer and back to H1 is PS+SH1. Later at time t2 when all three transducers have moved forward a distance $\underline{d}/2$, it can be seen that the new ray length from P to S and back to H2(PS+SH2) is identical to the first. Therefore the contribution of S to the signals r1(t1) and r2(t2) is the same, because it has the same amplitude and phase due to the same ray length. Now consider an infinite number of point scatterers, each one contributing to the two echoes received at H1 at time t1 or H2 at time t2. It is therefore possible to say $r1(t1) \simeq r2(t2)$ is valid, which shows that the received signal r2(t) is a delayed version of r1(t) by an amount t2-t1=T. We can therefore say that

$$\underline{V}T = \underline{d}/2$$

or

$$\underline{V} = \underline{d}/2T$$

which is the correlation log equation. The two detected envelopes R1(t) and R2(t) are described by

$$R1(t) = A1\left|r1(t) + n1(t)\right|_{LPF}$$

$$R2(t) = A2\left|r2(t) + n2(t)\right|_{LPF}, \quad r1(t+T) = r2(t)$$

where A1 and A2 are the gain factors of the receivers. Both the received signals r1(t) and r2(t) have additive noise n1(t) and n2(t) respectively, which may be background noise from the water or receiver noise. Figure 3 shows typical received envelopes.

The time delay measurement T is obtained by cross-correlating R1(t) and R2(t) after they have been quantised. Both the received signals r1(t) and r2(t) have additive noise n1(t) and n2(t) respectively, which may be background noise from the water or receiver noise. Figure 3 shows typical received envelopes.

The time delay measurement T is obtained by cross-correlating R1(t) and R2(t) after they have been quantised. Both R1(t) and R2(t) are quantised to 8-bit resolution, which should be sufficient provided there is no loss of accuracy during the correlation process. The quantisation noise is uncorrelated and will tend to cancel out in the correlation averaging process. However, the additive noise n1(t) and n2(t) may be correlated, and analysis is required for correlation in low signal-to-noise ratios. The reader is referred to Watts [2] for an analysis of amplitude quantisation with respect to correlation.

THE SYSTEM

The system comprises three main components as previously mentioned, a projector/hydrophone array, a rack mounted sonar and a microcomputer, as shown in Figure 1. The task of the microcomputer, which is an IBM PC-compatible model with an MSDOS operating system, is to control the sonar and to process the data received from it. Communication with it is by using 32 bytes of the input/output bus to read and write to peripheral registers; 16 bytes exist in the rack and the other 16 on the expansion card which plugs into the computer. A ribbon cable links the computer to the sonar which decodes the input/output bus for use. Figure 4 shows a block diagram of the sonar.

The main programming language for the system is PASCAL. Assembler is used in the interrupt handling routine, which is invoked when the analogue-to-digital converters have completed a conversion. The two 8-bit words read from the converters are stored in two arrays. The main program can then access these values and process them accordingly.

Projector/Hydrophone Array

The transducer array consists of a projector and two hydrophones, all of which are identical in construction and interchangeable. They consist of half-wavelength resonant piezoelectric elements, which give maximum efficiency for both projector and hydrophones. They are mounted in the array backplane and their relative positions are variable.

The individual elements are 20 mm-diameter piezoelectric ceramic discs made of PZT-4, with a 200 kHz nominal centre frequency. Each one is mounted in its own housing to ensure electrical isolation between the projector and hydrophones. The elements are air-backed, mounted in low density syntactic foam for support. This is enclosed in a circular Nylatron housing and unloaded epoxy resin is used as the acoustic window and also to seal the units. This arrangement gives a minimum possible separation of 50 mm between any pair of transducers when they are mounted in the array backplane. Locking clamps enable the transducers to be moved apart and re-clamped, thereby permitting a maximum separation between two transducers of 350 mm. This permitted different hydrophone separations and different hydrophone-to-projector separations to be used to study the effect of projector location on the correlation function.

During calibration it was found that the complete transducers were nearly identical, each with a resonant frequency of 218 kHz, a Q of 35 and a -3dB beamwidth of 23^{o}. The first sidelobes were found to be 20 dB down on the main lobe.

Tests taken in the water tank revealed negligble crosstalk between the projector and hydrophones. The isolation was found to be at least -90dB for all hydrophone positions.

Ray path analysis of the tank using the projector hydrophone beamwidth shows that valid echoes are received over the central portion of the track. Echoes received when the platform is within 1.5 m of the tank's two sides are not analysed; only those received during a travelling distance of 2.5m over its central position are used. Pulsed transmissions verify that multiple echoes do occur but these diminish by the sixth one, where they are lost in the background reverberation. There is some decorrelation between the two received signals because of this and the problem is currently being investigated.

Dual Channel Amplitude Demodulation Receiver

The purpose of the receiver is to boost the two hydrophone signals r1(t) and r2(t) to acceptable levels, to detect them and to generate their envelopes R1(t) and R2(t). The phase of the carrier is not important in this application. Each channel of the receiver consists of four parts (1) a high input impedance low-noise pre-amplifier, (2) a bandpass filter, (3) an envelope detector, and (4) a low-pass filter, as shown in Figure 5.

The pre-amplifier and bandpass filter have a combined voltage gain of 100 (+40dB). The bandpass filter removes excess pre-amplifier noise and eliminates extraneous signals, such as self-noise, from around the carrier frequency. This is an active resonant type based on an operational amplifier design. The centre frequency is tuned to 218 kHz and the bandwidth is approximately 20 kHz.

The envelope detector consists of a precision rectifier based on two operational amplifiers and has a voltage gain of 4 (+12dB) before detection. The output at this stage is now dc coupled, so offset voltages become important and an offset null capability is present. The low-pass filter boosts the video signal up to full scale range (+10v) and attenuates any residual carrier. The filter is a third order type with a corner frequency of 4 kHz.

The video output from the receiver has a full scale range of +10v dc; the corresponding input for this is 6.25 mV at 218 kHz.

The two video signals R1(t) and R2(t) feed the inputs to the digitiser.

Digitiser

The purpose of the digitiser is to quantise the two video channels to 8-bit resolution and to pass the two values to the micro computer at a given sampling frequency.

A programmable sequencer is used to generate the timing waveforms at 8-bit resolution and to pass the two values to the micro computer at a given sampling frequency.

A programmable sequencer is used to generate the timing waveforms at 8 different sampling frequencies ranging from 100 Hz to 4 kHz. The design is based on a ROM look-up table to generate the signals to control the sample-and-hold amplifiers and the analogue-to-digital converters. Once a conversion has been completed an interrupt is generated to the microcomputer, which then reads the values from the two ADCs and stores them in memory for later processing.

Stepper Motor Interface

The two stepper motors on the platform are driven by two drive cards running in parallel. The cards only need a Direction and Step signal to operate. The Direction signal is obtained by writing to a latch from the computer. A programmable interval timer (PIT) is configured as both a programmable frequency generator and a counter. This allows the Step pulse frequency to be variable in order to alter the motor speed, but it only sends a certain number of pulses to control the platform displacement. Once configured the PIT is entirely automatic in operation and the computer can carry out other tasks.

Carrier Generation

A sinewave at around 218 kHz is required to drive the projector at its resonant frequency. A 218.750 kHz signal is derived from a 14.0 MHz quartz oscillator by dividing its output frequency by 64 with a binary counter. The signal is Low-pass filtered to remove harmonics and obtain a sinewave. It is fed through a programmable attenuator to set the power level at the projector. Its output is buffered to drive an external power amplifier which powers the projector.

RESULTS AND CONCLUSIONS

Individual components of the system have been tested and they work satisfactory. They are currently undergoing integration, and system performance tests are presently being carried out. So far results from the sonar seem to be in accordance with expectations. At present only a rudimentary analysis of digitised echoes is being carried out. Correlation signal processing algorithms are being developed and it is intended that they should perform in real time, with the velocity measurement taken over a variety of platform speeds.

Analysis of the echoes for decorrelation effects due to the finite size of the tank is required. Ideally these should be compared with results obtained from open water and it is anticipated that open water trials will take place early in 1988. The system performance can then be analysed from a moving platform in an open expanse of water.

ACKNOWLEDGEMENTS

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REFERENCES

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[2] D. G. Watts, 'A General Theory of Amplitude Quantization with Applications to Correlation Determination', Proceedings IEE, Vol.109, Part C, 209-218, (1962).

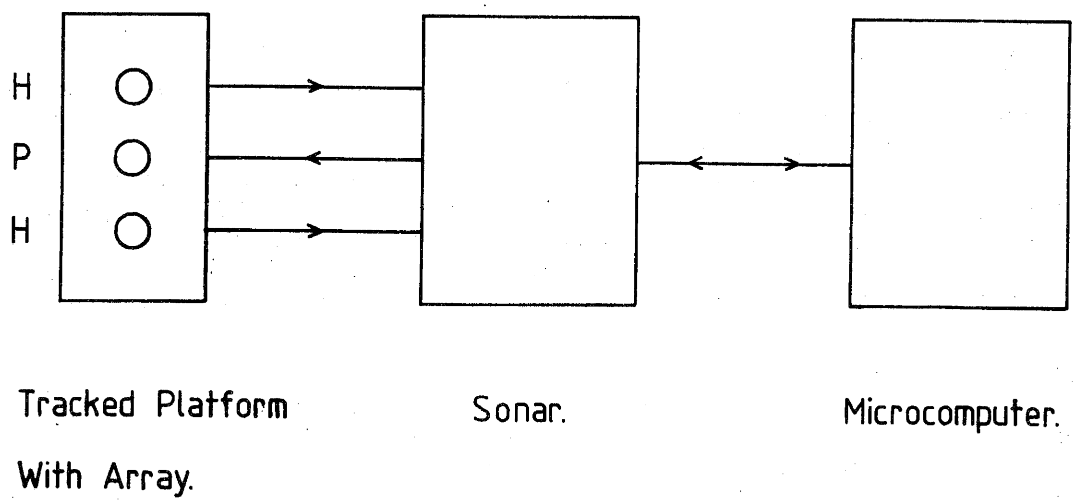


Figure 1 The System's Main Components.

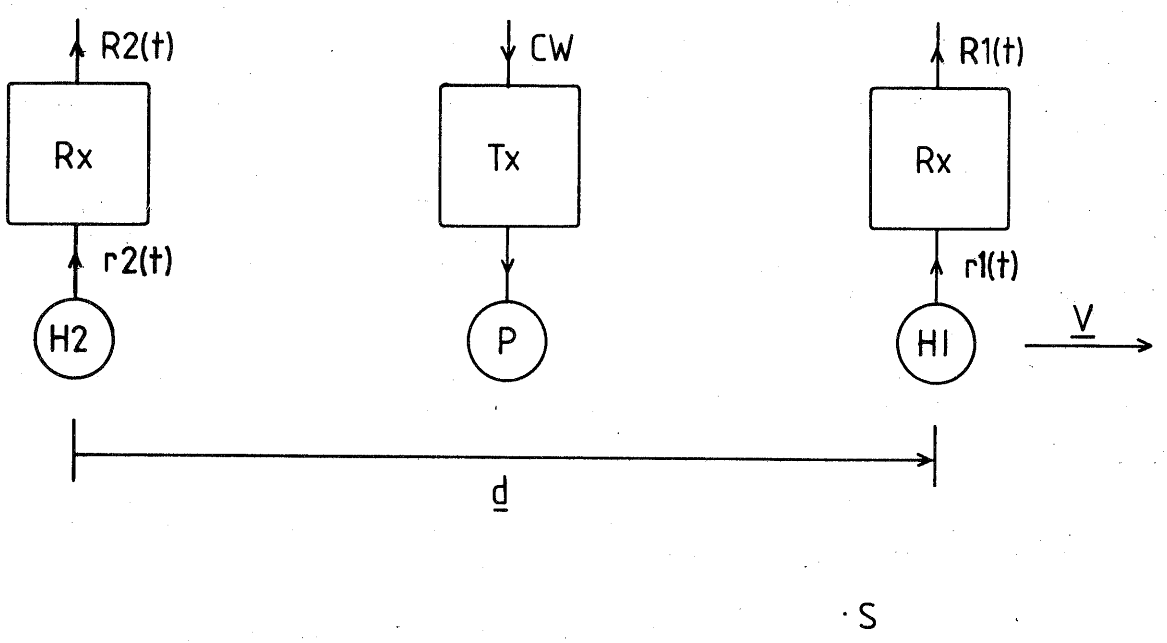


Figure 2 Array Geometry For Waveform Invariance.

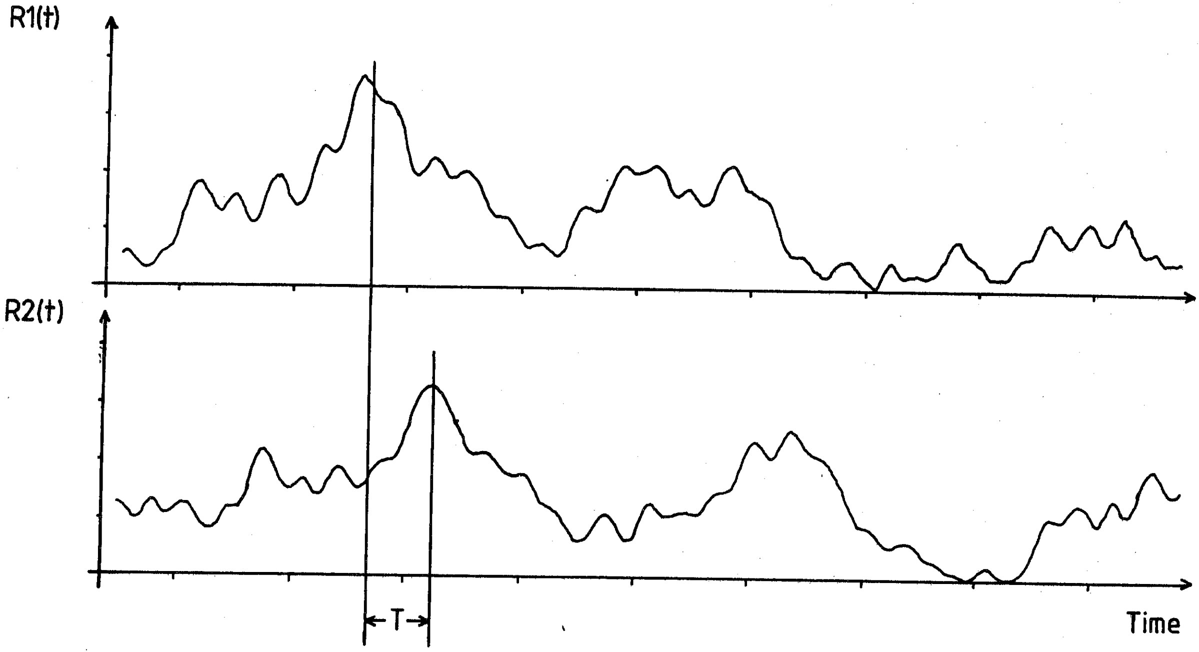
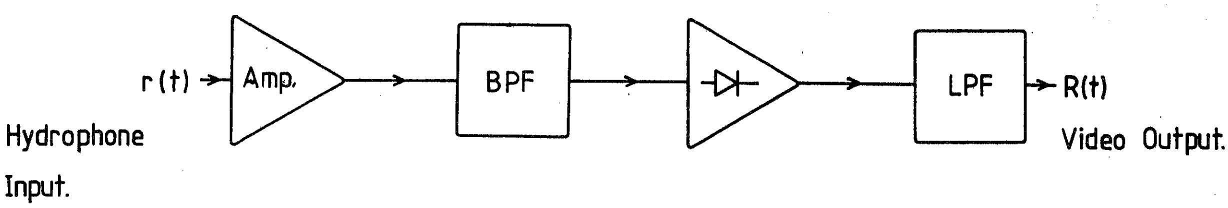


Figure 3 Typical Receiver Output Signals.



Pre-Amplifier	BPF	Detector	LPF (3rd Order)
Ao = 100	Bw = 20 KHz	Ao = 4.0	Bw = 4.0 KHz
	fo = 218 KHz		Ao = 4.0

Figure 5 Receiver Block Diagram (One Channel).

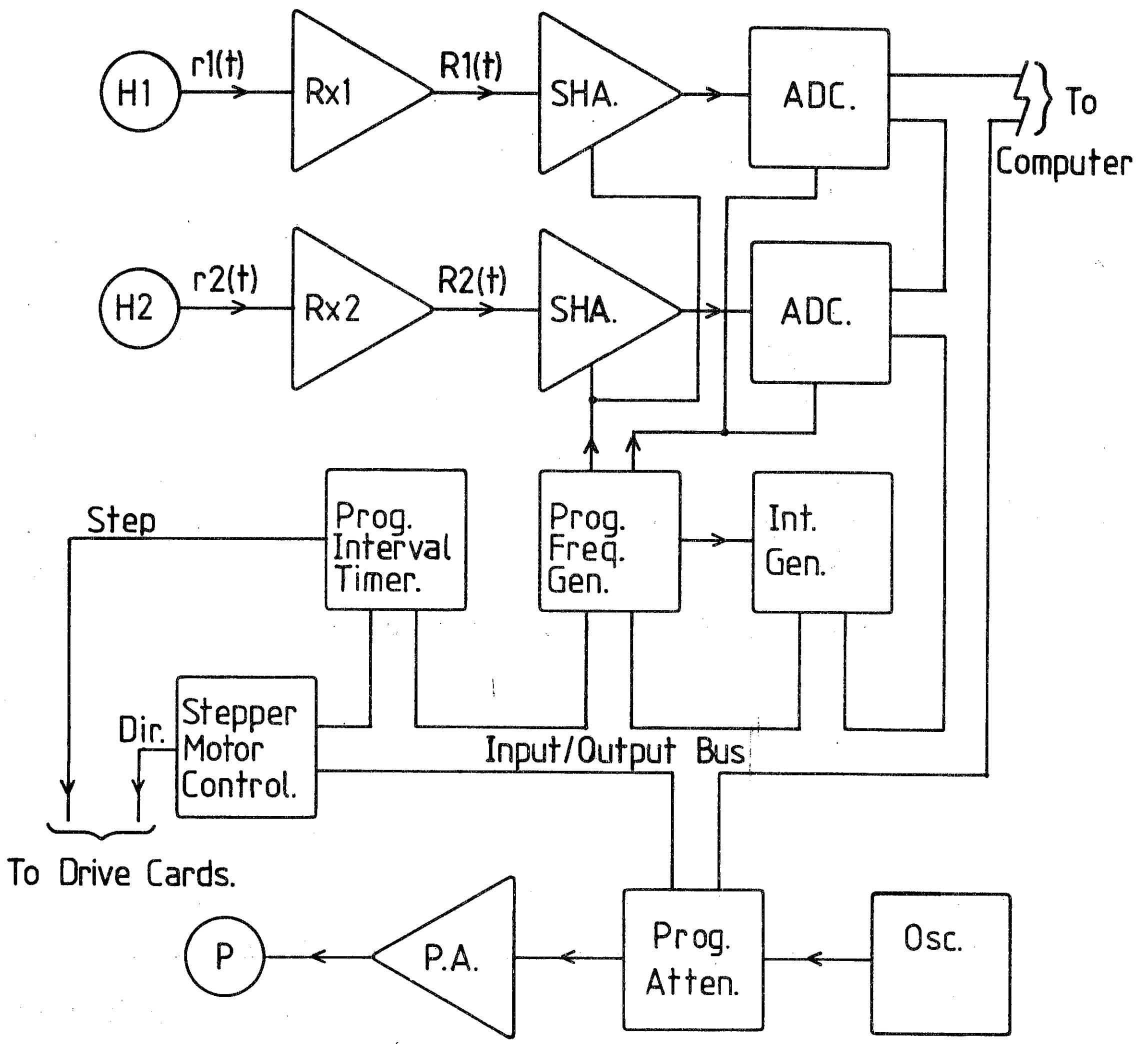


Figure 4 Sonar Block Diagram.