The Detection of Cylindrical Objects of Low Acoustic Contrast Buried in the Seabed

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Abstract: It is anticipated that the next generation of submarine fiber optic telecommunications cables will be invisible to present day detection systems. Research has been conducted into the remote detection of buried objects of low acoustic contrast, with particular emphasis given to the detection of buried cables. Specifically, this involves the design of a system that can reliably detect a small diameter (cm scale), cylindrical target buried to a depth of up to 1 meter below the seabed from a height of 1 meter above the seabed. A purpose-built, laboratory-scale, automated sensing system comprising a bistatic arrangement of adjustable, focused transducers has been used successfully in the high resolution imaging of a range of buried objects, proving an acoustic detection system to be a feasible solution. Recent experimental investigations have focused on two areas: Waveform optimization techniques, to maximize seabed penetration and target interaction; and matched-filtering and clutter reduction techniques, to optimize the detection system to the acoustic signature of a particular buried object.

INTRODUCTION

The need for a means of detecting buried objects of small size and low contrast is self-evident, whether on land or at sea. In the telecommunications industry in particular a need for advanced techniques for the detection of a new generation of telecommunications cables has become apparent (1). Unfortunately existing techniques, which have proven to be very successful on land (e.g., ground penetrating radar, thermal imaging), are severely limited in the underwater environment.

The overall requirement is for a remote detection system which can return information to facilitate the location and tracking of a buried, non-metallic, fiber optic cable. Detectors may be deployed from the cable maintenance vessel or operated from a seabed-crawling remotely operated vehicle (ROV). In this article the short-range tracking requirement is considered. The typical range when following a cable using an ROV is estimated to be around 2 - 2.5 m. For the purposes of the investigation, cables were assumed to be composed of glass fibers and polyethylene and to have a minimum diameter of 10 mm, though experiments have also been conducted using a range of objects including steel spheres and cylinders.

Of great concern in any detection system is the problem of maximizing backscatter from the target. A solution may be afforded by exploiting the distinctive geometric and resonant scattering characteristic of the target. In the case of a multi-layered telecommunications cable the resonant part of the spectrum cannot be easily determined. However, the feasibility of a detection system can be investigated using homogeneous cylindrical targets, for which the resonance spectrum can be determined (2).

THEORY

Continuous wave detection systems are capable of accurate velocity measurement. Conversely, pulsed systems are capable of accurate range measurement. Velocity measurement was not a primary concern in this study so a pulsed system was chosen. Pulse expansion / compression and matched-filtering techniques have been investigated as a means of producing a higher total output power than could be achieved using short pulses (due to the peak power limitations of the transducers) with no loss in range resolution (3).

The matched-filter is known to be an optimal pre-detection filter in the presence of Gaussian white noise. It transforms the raw data at the receiver into a form that is suitable for performing optimum detection decisions. It may be assumed that the target region (i.e., the seabed) is composed of small, independent, broadband scatterers of random size and location, spaced much closer than the waveform resolution capability of the matched-filter output. In an extended region of densely packed scatterers such as this, the clutter signal has the characteristics of random noise due to the overlap of the many individual signals that are present. The general optimization of the matched-filter for stationary or slow moving clutter, $H(\omega)_{\mathrm{opt}}$, is given by

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$$H(\omega)_{\text{opt}} = \frac{S^*(\omega)}{\frac{N_0}{2} + K_c|S(\omega)|^2} \quad (1)$$

where $S(\omega)$ is the spectrum of the known signal function, N_0 is the one-sided noise power density and $K_c|S(\omega)|^2$ is the clutter power spectrum. If the scattering characteristic of the target can be determined it is possible to modify the filter signal function to match the target signal at the receiver input. Much effort has been put into the determination of the scattering characteristics of the buried cylinders used in this study.

The question arises as to whether there is a waveform that will maximize the signal-to-noise ratio at the filter output and achieve a high accuracy in terms of range resolution. As a general rule, the best performance in a densely cluttered environment is achieved by using a signal with a wideband spectrum of uniform height. The linear FM pulse tends to exhibit such a spectrum and, for the case of densely packed scatterers that are not moving rapidly with respect to the target, it approximates the optimum bandlimited waveform (4).

EXPERIMENTAL RESULTS

The apparatus represented a scaled version of the "at-sea" environment. It comprised a water-filled tank containing saturated sand to a depth of around 50 cm. A bistatic arrangement of small (35 cm diameter), spherical reflectors (5) were used to focus the acoustic energy transmitted and received by a pair of hydrophone transducers, thus increasing the signal-to-noise ratio and achieving a narrow beamwidth. The transducers were positioned at a height of 23 cm above the sand and the reflectors inclined at an angle of 30° to normal incidence.

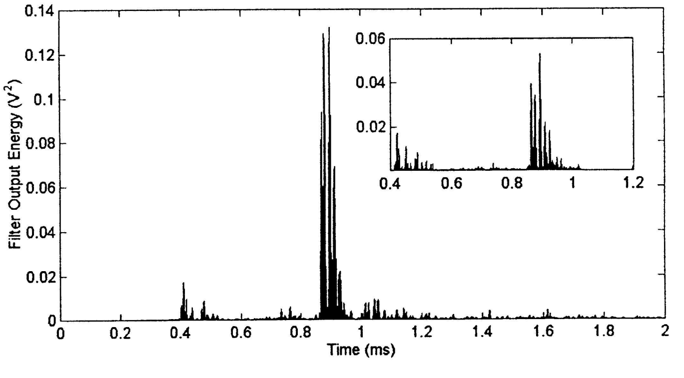

FIGURE 1. Energy at the matched-filter output for a cylindrical target and, inset, the filter output when no target is present.

An example of the matched-filter output is shown in figure 1. A linear FM pulse (bandwidth, 20 kHz - 120 kHz; time duration, 1 ms) was directed towards a steel cylinder, 25 mm in diameter, buried at a depth of around 28 cm beneath the sand. The filter was adjusted to the theoretical scattering characteristic of the target. The predicted time-of-arrival of the target pulse coincides with the large peak at around 0.9 ms. The inset graph shows the output of the same filter when no target is present. A peak is still seen to occur, due the focusing effect of the transducers, but at a significantly lower level. It has been concluded, from this and similar results, that this technique can yield excellent results when applied to the detection of buried objects in a cluttered medium, provided that their scattering characteristics are known in advance.

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