DIGITAL FILTERING OF ULTRASONIC ECHO SIGNALS FOR INCREASED AXIAL RESOLUTION

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Introduction

Digital processing of ultrasonic signals offers powerful tools to improve the quality of ultrasonic images. The ultrasound pulse echo method is now widely used in medical diagnosis. The axial resolution however is strongly dependent on the duration of the transmitted ultrasonic pulse. Increased resolution can be obtained by taking the shape of the transmitted pulse into account in the processing of the received echo signal.

The approach described in this paper is to design a digital filter as shown in Figure 1. The aim is to decrease the duration of the echo pulses. Ideally, the filter converts a single echo pulse to a very sharp output pulse. The choice of an appropriate desired output shape can be difficult in practical applications. A similar technique applied to ultrasonic signals is described in [2] where the desired output has a Gaussian shape.

Method

The major problem in designing pulse shaping filters is to define the desired output shape suitable for various forms of inputs. However, there are three important components of this problem

1. The output must have a high amplitude at one point, say for \( t=0 \).
2. The amplitude of the output must be low outside some desired resolution interval.
3. The output noise must be low.

The filter which solves (1) and (3) is the well-known matched filter. However, from this filter the output signal usually has such a long duration that (2) cannot be achieved in a satisfactory way. If (2) specifies the highest possible resolution, the filter which solves (1) and (2) is the inverse filter \([1]\), but this filter is very sensitive to the noise. Furthermore, even in the noiseless case the result is not suitable for this signals since the inputs have no low frequency components. Combining (1), (2) with the desired resolution interval \( T \) on each side of \( t=0 \), and (3)
with the expected noise power \( w_o \), we use the least squares cost function

\[
J = (1-s(t)u(t))_t^{2} + \sum_{t>T} (s(t)u(t))^2 + w_o \sum_{t} u(t)^2
\]

where \( s(t) \) is the input signal and \( u(t) \) the filter to be designed. This filter we have called the weighted least squares filter [1]. The three parts of the above equation corresponds to the three given statements, respectively. The suitability of the weighted least squares formulation is that the two selectable parameters \( T \) and \( w_o \), relate the inverse filter to the matched filter [1].

**Results**

An example of this technique is shown in Figure 2a and b. The transducer impulse response is shown in Figure 2a. This signal is measured from a reflection between plexiglass and air. The sampling rate was 8.33 MHz. Figure 2b shows the output from a weighted least squares filter with \( T=6 \) sample points (0.7 \( \mu \)s) and a signal to noise ratio of about 100. As expected, the duration of the output signal is shorter than the duration of the input signal.

The weighted least squares filter formulation is well-suited to the ultrasonic pulse echo problem. Results of using the filters for increased resolution of complex echo structures will be presented.

**References**

[1] B. Mändersson

"Weighted Least Squares Filter - A Modified Approach to Least Squares Pulse Shaping Filters",

to be published.


"Digital Processing of Ultrasonic Data by Deconvolution",

Figure 1. The principle of filtering of ultrasonic echo signals for increased axial resolution.

Figure 2. An example of input and output. The broken lines are the envelopes.
   a) The impulse response of the ultrasonic transducer.
   b) The output signal from a single echo (noiseless case).