Online median filter for ultrasound signal processing

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1 Introduction

The application of linear smoothing filters for reduction of unwanted noise in the ultrasound images is a well known method. These filters inevitably smooth the contours of the picture content too, thus degrading the resolution. The use of nonlinear smoothing filters could overcome this disadvantage to a certain extent. Median filtering is an image-processing technique of this type (Collins and Skorton, 1986). The median value of a set of $2n + 1$ signal samples is obtained when the values of these samples are ranked in ascending order and the value corresponding to position $n + 1$ is taken.

The application of two-dimensional filters in an online mode during ultrasound image formation and processing is impeded due to the complexity of the necessary hardware. Software filtering is limited only to frozen image processing (Sai Prasad and Srinivasan, 1986).

The image quality in real-time mode can be improved using a one-dimension filter applied to the signal of each ultrasound beam. A three-point 'beam filter' of this type is proposed.

2 The filter

The filter's block diagram is shown in Fig. 1a. The sample values $X(n-1)$, $X(n)$ and $X(n+1)$ are stored in the registers 1–3. Register 1 is also a buffer between the AD converter and the filter. The three magnitude comparators 1–3 as well as the logical circuits connected to their outputs $q_1$, $q_2$ and $q_3$ determine the code $s_0$ or $s_1$ of the register, where the median value is stored. The content of this register is transferred into register 4 by the multiplexer. The data at the output of register 4 appear delayed with one clock period. The filter can be switched off by the signal on/off.

A possible implementation of the magnitude comparators 1–3 using standard integrated circuits is shown in Fig. 1b.

The filter is designed for 6-bit input data because this is the resolution of the AD converter of the scanner used. Of course a higher resolution filter can easily be implemented, as well as a higher order one, using the same approach. The maximum clock frequency for the filter operation is determined by the delay in the comparators and the multiplexer.

In our experiments, the filter, except register 1, is built using the single chip erasable programmable gate array EP1800. The clock frequency can be up to 10 MHz.

3 Experiments

The filter has been tested using a linear ultrasound scanner developed in our laboratory. The analogue signal from the ultrasound transducer is amplified and fed to the AD converter. The AD converter output data are processed by the digital scan convertor (DSC), where the two-dimensional image is formed. The median filter is inserted between these two modules (Fig. 2). A DA convertor is connected to the filter output (Fig. 2) to obtain observable output signals, using a two-channel digital storage oscilloscope.

The signals at the input of the AD converter and at the output of the median filter are shown in Fig. 3a. An ultrasound tissue equivalent phantom (composite test object from Diagnostic Sonar Ltd.) is used. The echo signal is obtained from reflecting rods of 0.15 mm stainless-steel wire, placed in the phantom at a distance of 5 mm one from another. The sampling frequency of the AD converter is 2.53 MHz. The output signal from the filter is shifted with respect to the input analogue signal, due to the delay in the AD converter, the register 1 and the filter.

The operation of the median filter is compared with a Hanning finite impulse response (FIR) filter. For this purpose, the input of the linear filter is connected in parallel to the median filter input. The equation of the linear filter is (Tomkins and Baharestani, 1981):

$$Y(n) = 0.25X(n-1) + 0.5X(n) + 0.25X(n+1)$$

To compare both filters, a second DA convertor is used at the output of the linear filter. The responses of both filters to one and the same input signal (not shown in the figure) are shown in Fig. 3b.
The filter efficacy in bidimensional presentation can be assessed fully in real-time mode only. The frozen images of the test object in Figs. 4 and 5 give a limited possibility for assessment of the filter function. In Fig. 4 an unfiltered image (left) is compared with a filtered one using the median filter. The noise, better seen in the depth 11–20 cm, has been effectively filtered out. The structure of higher density is more uniform in the filtered image (the speckle is smoothed) and the targets are practically of the same appearance in both images.