c Letters to the Editor-in-Chief

A Note from the Editor-in-Chief:

Until now, the publication in the journal of a Letter to the Editor-in-Chief has been quite a rare event. When the Editor receives such a Letter, if it relates to an article previously published in the journal, a copy is sent to the corresponding author concerned. This provides the opportunity for a response to be published at the same time as the original Letter. Apart from making sure that nothing obviously inappropriate is published, the Editor does not intervene in this process. What is published as a Letter is not subjected to peer review. The justi®cation is that such a published Letter is itself an integral part of the peer review process. In principle, the process can go through several cycles, with each pair of published Letters leading, in a subsequent issue of the journal, to a further pair of Letters, until the Editor brings the correspondence to an end.

The journal does not currently have a policy concerning the length of an individual Letter. Notice is now given, however, that Letters that would occupy more than two printed pages in the journal will not normally be accepted for publication in the future.

P.N.T. WELLS

COLOR FLOW MAPPING

To the Editor-in-Chief:

This letter pertains to the review article ``Color ¯ow mapping'' by Ferrara and DeAngelis (1997), which was published in this journal (1997;23:321±345). The topic is timely and important; however, while reviewing the alternative velocity estimation techniques in the literature, the authors unfortunately have omitted many important contributions to the ®eld.

This in,[9945ualothe contr45ua248(`` [(journal)missithe)968(frome)968(e®e6)-248(artie6)--248(``Co968(eoCo968(33dvidee)96 sound that also discussed many intricate technical issues involved with velocity estimation. Burns (1987) and Magnin (1987) provide excellent overviews of conventional Doppler methods. Jensen (1996) and Jones (1993) also provide a comprehensive overview of the estimation of blood velocity with ultrasound. Kremkau (1990, 1991) and Wells (1994) provide excellent summaries of color ¯ow applications.

2) The time domain methods. The relative shift in echoes due to target movement between two successive ®rings also can be used to estimate ¯ow. Two groups independently implemented cross-correlation search to estimate this shift (Bonnefous and Pesque 1986; Foster et al. 1990). Because the correlation search is computationally intensive, a one-bit version has been implemented commercially for real-time operation (Bonnefous et al. 1986; Rickey et al. 1992). To reduce the computational complexity for the correlation search, a SAD algorithm has been proposed (Bohs and Trahey 1991). Time domain search methods generally use wide-band pulses and do not suffer from aliasing. de Jong et al. (1990) developed a narrow-band method that computes the correlation coef®cient function only at ®ve points in the vicinity of the maximum, and uses an interpolation algorithm to evaluate the location of correlation maximum from these points. This method requires signi®cantly less computation compared to correlation search; however, it does not work well with large bandwidth signals, and it suffers from aliasing. This technique has been evaluated in an experimental set-up with a rotating agar disk containing scattering particles (de Jong et al. 1991). Jensen (1991, 1993, 1994) discussed the performance, limitations and artifacts associated with the time domain correlation methods for tissue motion estimation. A comprehensive review of the time domain methods can be found in Hein and O'Brien (1993).

3) Multiple-burst (tracking) methods. These methods are based on both the phase change and the relative shift in the echoes. Recall that the frequency/phase domain methods use the change of phase over many transducer bursts from only a ®xed sample volume, whereas the time domain methods, at least in the simplest implementation, try to estimate the tissue movement through the time shift between two successive pairwise transducer bursts. However, the new tracking methods try to track the target movement using various algorithms through many transducer bursts. In this model, the radio frequency (RF) echoes due to many transducer bursts are stacked together to form a two-dimensional (2D) array (``slow time'': transducer burst index, ``fast time'': depth). The 2D array thus created may be processed in a variety of ways to obtain a ¯ow estimate. These are generally wide-band methods, but some suffer from aliasing. There have been many contribution to this area; however, the authors of the review failed to discuss any work in this area other than their own. To the best of our knowledge, Wilson (1991) was among the pioneers in this group of methods. He proposed using the 2D Fourier transform on the 2D RF array. It was shown that the 2D Fourier transform would be nonzero only along radial line segments on the frequency plane whose slope is proportional to the scatterer velocity. A method to overcome the associated frequency aliasing problem also was discussed. A different matched ®lter approach referred to as the wide-band maximum likelihood estimator (WMLE) was developed by Ferrara and Algazi (1991). The likelihood for velocity v was given by:

$I(v)$ 5

1996). In one method, the multiplication of the complex

Being a matched-®lter approach, WMLE needs an accurate signal model to work well (parametric method). The other methods in this group are not as susceptible because these methods do not require the received signal shape to be known (nonparametric methods). In general, the shape of the received echo changes due to the changes in the center frequency and bandwidth in the signal for various effects including frequency-dependent attenuation and scattering, changes in the beam and different arrival time of the signals from different areas of the transducer except at the focus. In general, these changes are not precisely known.

Loupas and Gill (1994) analyzed the problem of 2D spectral analysis for discrete limited-duration signals. Loupas et al. (1995a, 1995b) introduced a 2D autocorrelation approach for the axial velocity estimation. The mean axial velocity is estimated from the estimates of both the Doppler and RF mean frequencies. Thus, this can potentially overcome the estimator bias due to frequency-dependent attenuation discussed by Ferrara et al. (1992). The 2D autocorrelator can be applied to both the complex envelope and the analytic RF signal. The results from simulation showed that 2D autocorrelator performs much better in the presence of modest velocity spread and high SNR; however, these enhancements become marginal as the condition degrades, which worsens the correlation between Doppler and RF ¯uctuations. The 2D autocorrelator and the cross-correlator are shown to be mathematically equivalent under a set of speci®c conditions. They were found to perform in an identical manner in high SNR conditions; however, the former was found to be more robust in low SNR conditions.

For presenting quantitative blood velocity information, Doppler spectrum analysis with a velocity-time display has proven to be very robust and accurate (Torp and Kristoffersen 1995). These authors presented a tracking method that suppresses frequency aliasing in the Doppler spectrum velocity-time display. They demonstrated that tracking in 2D transform space, as described by Wilson (1991), can be shown to be equivalent to a tracking in 2D (slow time±fast time) space.

Thus, several tracking methods have been developed. They have all been found to perform well. Some of these methods suffer from notable limitations, including aliasing effects in the 2D FFT and the necessity to know the received signal shape in the WMLE, and some of these methods are computationally intensive. However, the butter¯y search can be implemented in parallel and with elementary digital operations.

We hope this discussion of tracking methods has helped to overcome the shortcomings of the review article and has provided a complementary perspective.

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S. Kaisar Alam

Department of Radiology
University of Texas Medical School
6431 Fannin St., Suite 2.100
Houston, TX 77030, USA

Kevin J. Parker

Department of Electrical Engineering
University of Rochester
Rochester, NY 14627, USA

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IN RESPONSE TO S. K. ALAM AND K. J. PARKER

To the Editor-in-Chief:

I appreciate the opportunity to review and comment on the Letter to the Editor by Alam and Parker, which provides a perspective on the review article ``Colour Flow Mapping.'' Our article includes a broad overview of many aspects of color ¯ow mapping instruments including clinical applications, limitations of current instruments, sources of error, system architecture, transducers, safety, color maps, contrast agents and several aspects of signal processing. With the suggested outline, diverse potential audience and proposed page budget, a detailed review of velocity estimation techniques was not possible. Given the very general nature of the article and the brief paragraph describing our velocity estimation technique within it, the detailed discussion of speci®c techniques in the Letter by Alam and Parker seems misplaced as a response to our article. Also, our paper was submitted in early February 1996 and accepted in March 1996. Thus, two of the three Alam and Parker articles, as well as the book by Jensen, had not yet been published when we submitted the paper. This does not imply that additional excellent articles could not be referenced in every area of the review. Indeed, this is probably the case for every review article currently in print.

The framework for the signal processing discussion in our article is based on the classical work of (Van Trees 1968), which has the advantage of providing general expressions for local and global error without subclassi®cation for pulsed transmitted signals. This framework also avoids differentiation of time and frequency domain techniques. Because estimators such as the autocorrelator can be derived in either domain, this distinction seems less useful in our application. In addition, our article indicated that the Van Trees formalism leads to guidelines for systems that may track red blood cells.

Beyond this, I certainly agree that the WMLE (Ferrara and Algazi 1989) is very similar to the butter¯y technique (Alam and Parker 1995) and that it is always interesting to examine multiple paths for deriving signal processing strategies. It seems best to leave detailed analyses of signal processing techniques to the peer-reviewed literature, but I will brie¯y address points that could be misinterpreted in the Letter by Alam and Parker. The Letter described three ``key'' modi®ca-