Ultrasound Speckle Reduction After Coded Excitation and Pulse Compression

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Introduction

Ultrasound images are riddled with system-dependent imperfections called speckle, the salt and pepper appearance in the image. Speckle is an inherent property of the ultrasound imaging system, not the subject being imaged.

Objective

Reduce the appearance and influence of speckle in ultrasonic images through post-processing techniques to improve the quality of the image.

Motivation

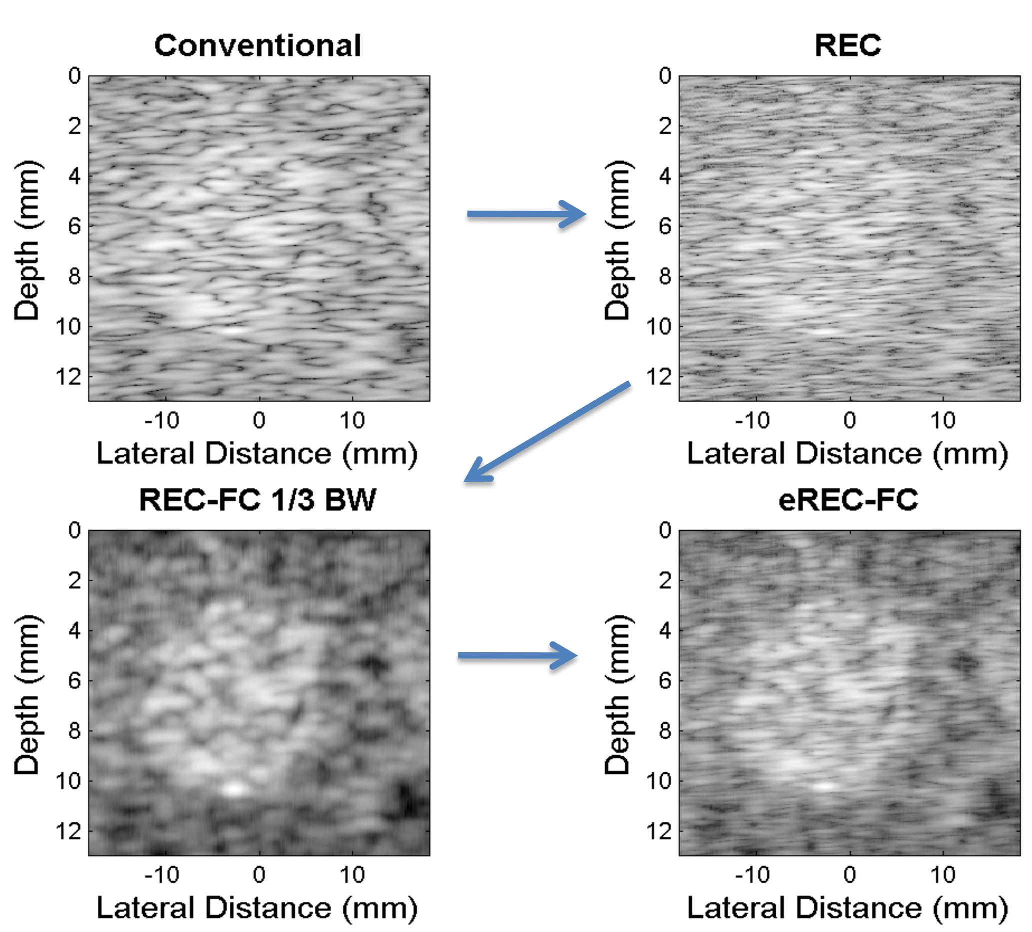
A recently developed speckle reduction imaging technique known as eREC-FC [1], which uses coded excitation, has three defining characteristics. First, the resolution of the image is maintained; second, the contrast-to-noise ratio (CNR [2] – describes how well a tumor is perceived compared to the surrounding tissue) in the image is improved over the conventional ultrasonic image (CP) by a factor of two; and finally, speckle is reduced. The speckle remaining in the eREC-FC images can be further reduced by applying post-processing despeckling filters, consequently improving image contrast while maintaining key features in the ultrasound image.

Significance

Identification of small lesions or tumors that have a small contrast differences from the surrounding tissue could be identified earlier.

eREC-FC Overview

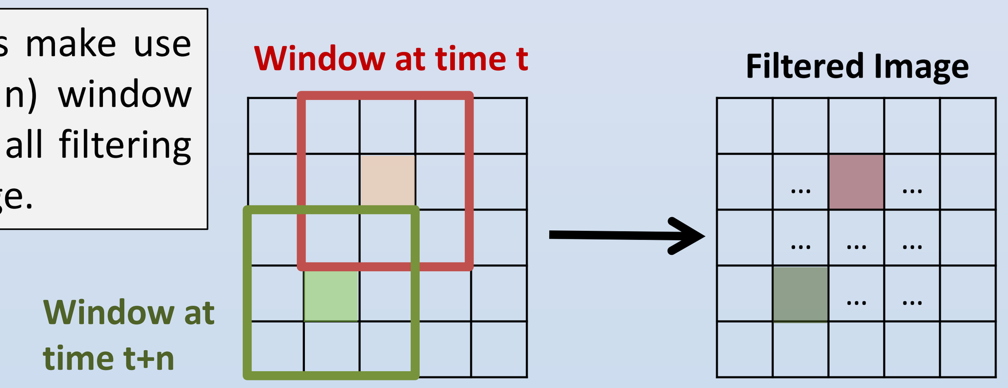
The image-to-image process of eREC-FC imaging is shown below.



Filter Descriptions

Overlapping, Moving Window

Some filters make use of an (n x n) window to perform all filtering on the image.



Median [3]

-Makes use of an (n x n) window, where n is odd.

-Center pixel of window in filtered image is the median.

Lee [4]

$$\sigma_n^2 = \sum \frac{\sigma_{w_{big}}^2}{\overline{w}_{big}}$$

$$p_{filt} = \overline{w} + k \cdot (p - \overline{w})$$

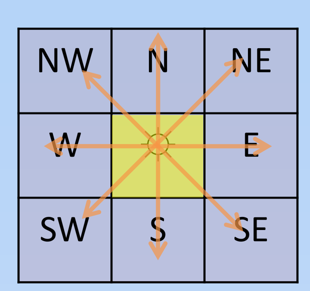
$$k = \frac{1 - \overline{w}\sigma_w^2}{\sigma_w^2 \cdot (1 + \sigma_n^2)}$$

-Makes use of an (n x n) window, where n is odd.

-Estimate noise (speckle) variance, $\sigma_{w_{big}}^2$, in image with a bigger window, w_{big}.

-Use local statistics to calculate new pixel, p_{filt}, based on the overlapping, moving window's, w, mean, a scaling factor, k, and the middle pixel of w, p.

Geometric [5]



-Uses a 3x3 window.

-Iterative approach, based on direction (N-S, E-W, NW-SE, NE-SW).

-Compare 3 pixels along a line.

-Make center pixel more like its neighbors: adjust value by ±1, depending on if below or above neighbor, respectively.

Speckle reducing anisotropic diffusion (SRAD) [6]

$$\begin{cases} \frac{\partial I}{\partial t} = div[c(|\nabla I|) \cdot \nabla I] \\ I(t=0) = I_0 \end{cases}$$

$$c(x) = \frac{1}{1 + \left(\frac{x}{k}\right)^2}$$

-Anisotropic diffusion algorithm that smoothes image in homogeneous regions but preserves edges.

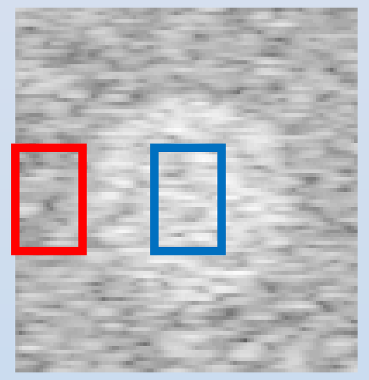
-Solve nonlinear partial differential equation based on divergence, diffusion function $c(x)$, instantaneous coefficient of variation, and gradient of the image, I.

Contrast-to-Noise Ratio

$$CNR = \frac{|\mu_B - \mu_T|}{\sqrt{\sigma_B^2 + \sigma_T^2}}$$

Calculated from the mean and variance of two windows - one window on the background and one on the target.

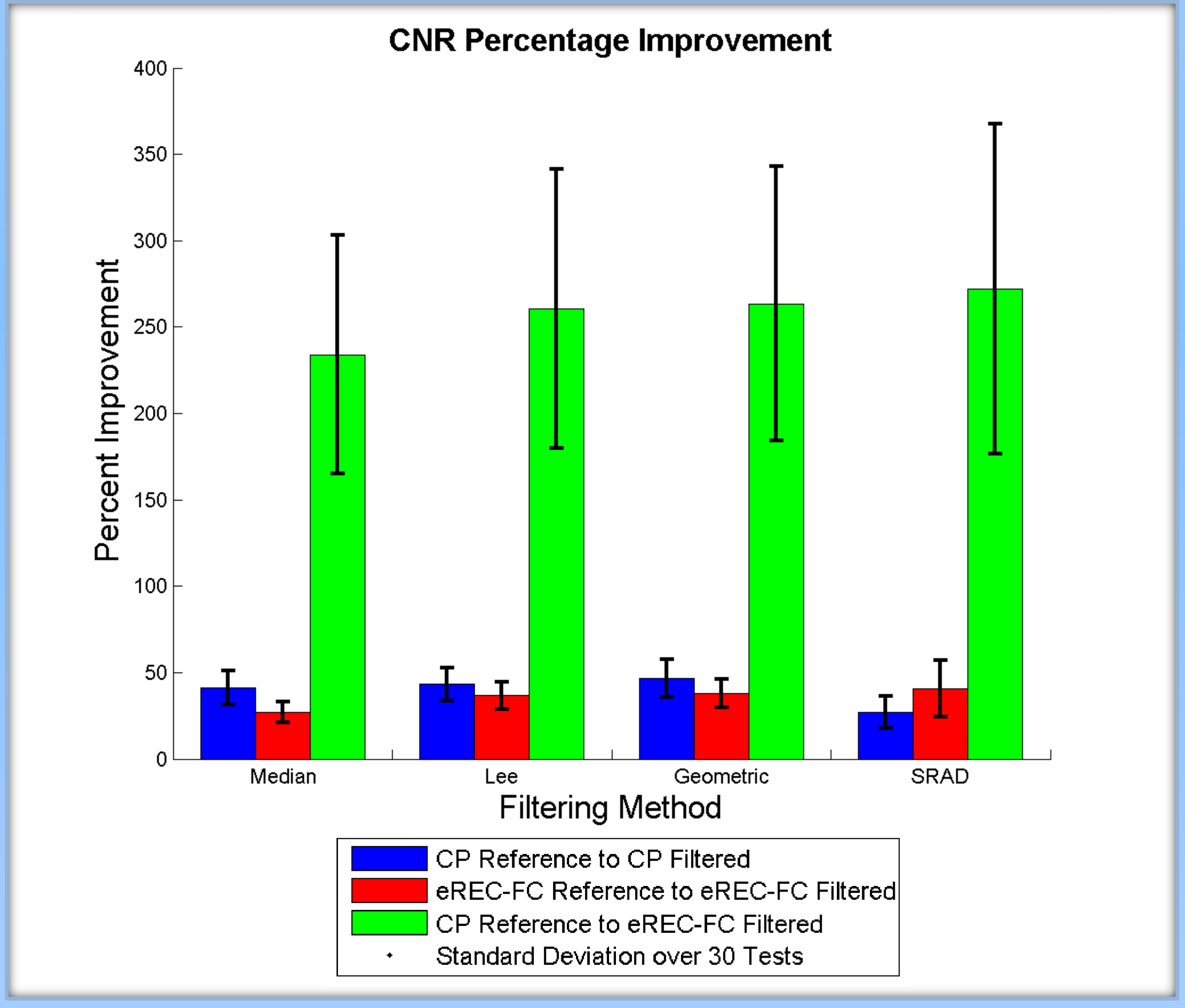
Used to quantify how well an object stands out from the background.

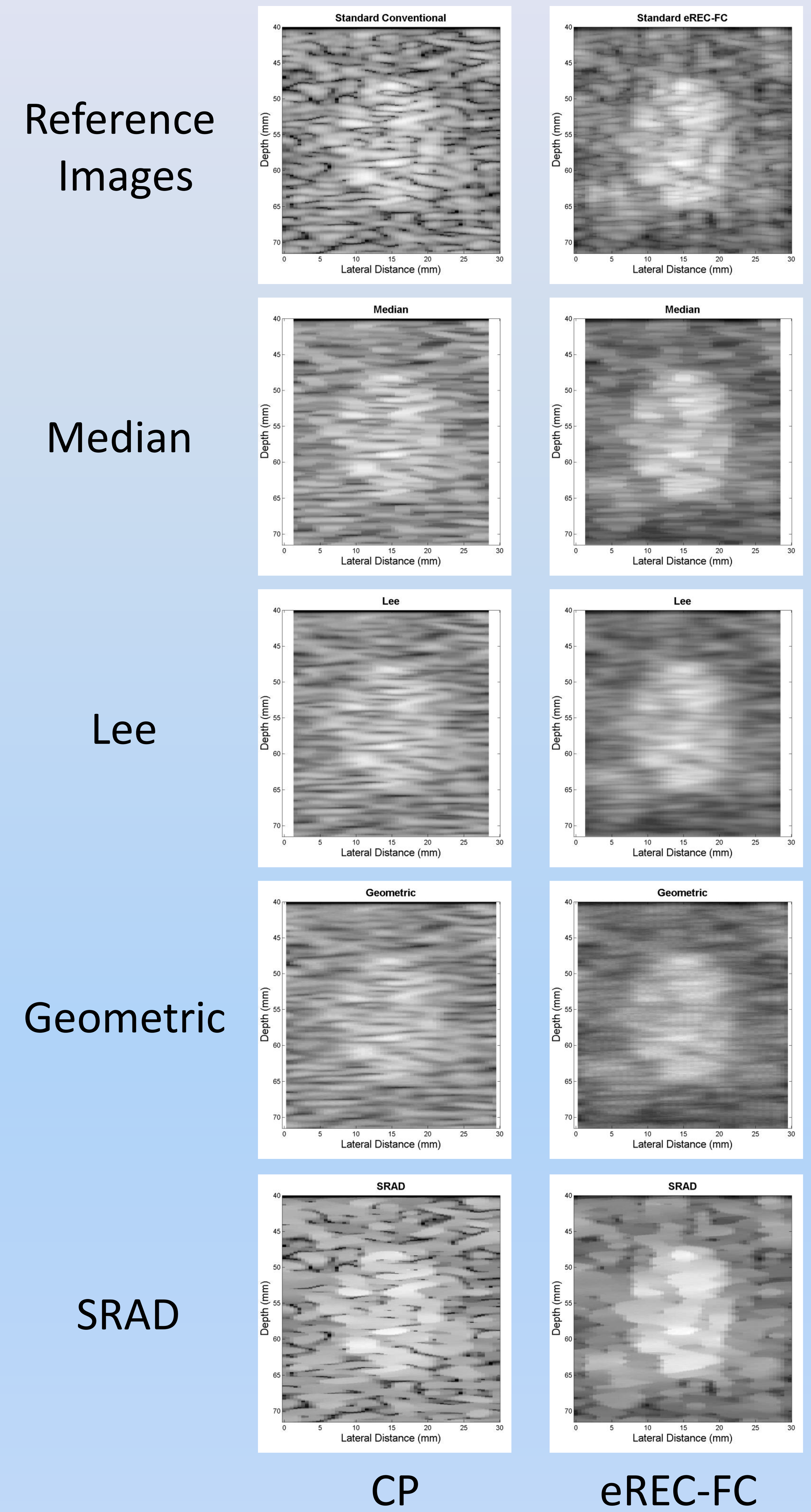


Simulations and Results

The aforementioned filters were applied to 30 different simulations. CNR was calculated on the reference images and on all images after the post-processing filters were applied.

Shown below is the average improvement of each filter and standard deviation for all simulations. Shown to the right is a complete simulation to present the qualitative effects of each filter on both the conventional (CP) reference and eREC-FC reference images.





Conclusions

The CNR values suggest that the SRAD filter resulted in the best contrast improvement. The significance of improving the contrast of eREC-FC images with post-processing filtering is that small and low contrast lesions that may not be visible in a conventional ultrasound image are enhanced. Consequently, speckle reduction techniques could improve the capabilities of diagnostic medical ultrasound system for earlier *cancer detection*. To further validate the results, other image quality metrics will be used to quantify image features such as blurring and edges.

References

[1] J. R. Sanchez, "Improving ultrasound imaging using novel coded excitation techniques," Ph.D. dissertation, University of Illinois at Urbana-Champaign, Urbana, IL, USA, 2010.

[2] M. S. Patterson and F. S. Foster. "The improvement and quantitative assessment for B-Mode images produced by an annular array / cone hybrid," *Ultrason. Imag., vol. 5, no. 3, pp. 195-213, Jul. 1983.*

[3] M. O. Ahmad and D. Sundararajan, "A fast algorithm for two-dimensional median filtering," *IEEE Trans. Circuits and Syst., vol. CAS-34, no. 11, pp. 1364-1374, Nov. 1987.*

[4] C. P. Loizou, C. Christodoulou, C. S. Pattichis, R. Istepanian, M. Pantziaris, and A. Nicolaides. "Speckle reduction in ultrasound images of atherosclerotic carotid plaque," *14th International Conference on Digital Signal Processing, 2002, vol. 2, pp. 525-528, 2002.*

[5] L. J. Busse, T. R. Crimmins, and J. R. Fienup, "A model based approach to improve the performance of the geometric filtering speckle reduction algorithm," *IEEE Ultrason. Symposium, pp. 1353-1356, 1995.*

[6] Y. Yu and S. T. Acton, "Speckle reducing anisotropic diffusion," *IEEE Trans. Image Process., vol. 11, no. 11, pp. 1260-1270, Nov. 2002.*