AMPLIFYING FEATURES IN SPM IMAGES USING A CONTINUOUS WAVELET TRANSFORM

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One traditional method to analyze noisy SPM images is based on Fourier decomposition. Selection of dominant Fourier coefficients followed by reconstruction allows a visualization of many features of interest in SPM images. This method is widely used even though indiscriminate use often produces spurious artifacts that can be misleading. We present here a complementary method to analyze SPM images based on wavelets.

Fourier decomposition provides information about the contribution of different length scales to the image under analysis. Assuming that properties do not change throughout the entire image, Fourier analysis techniques are very powerful to separate the noise and signal contributions. However the lack of local information can make the extraction of desired features difficult in some cases. An alternative approach, wavelet analysis, is achieved by convolving an image with a wavelet characterized by a particular shape and size. As a result, information about the contribution of different scales (selected by the size of the wavelet) is obtained at every location in the image. Moreover, features resembling the shape of the wavelet will be enhanced by the convolution. As an example, Figure 1 compares the performance of Fourier and Wavelet based techniques on the removal of white noise from simulated atomic scale corrugation in SPM images.

We have also performed a realistic simulation of scanning probe data that includes the presence of 'streaks' or 'scanning tears'. Scanning tears produce significant Fourier coefficients that will mask those associated with the desired signal. An example is presented in Figure 2. Removal of Fourier coefficients dominated by the scanning tears can create artificial features based on the assumption of uniformity of structure in the overall image. Wavelet analysis of the same image reproduces the underlying structure quite accurately.

The wavelet based method we have developed has been incorporated in the Nanotec Electronica, S.L. WSxM Software package and is therefore available for use by any SPM user.

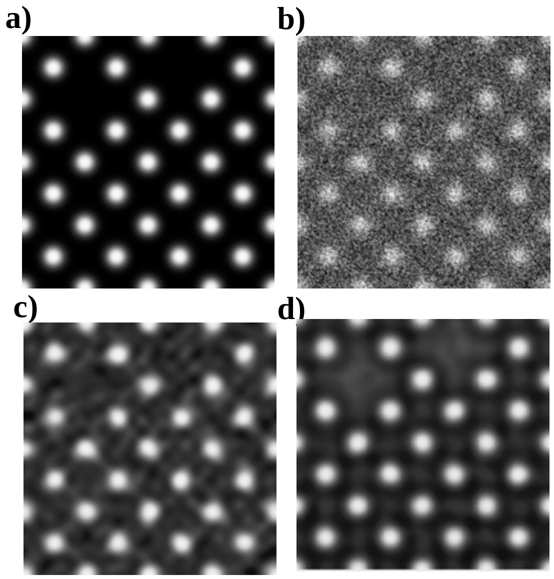

Figure 1: An example of the removal of white noise from atomic scale corrugation in SPM images. In (a), a simulated grayscale image of a periodic array of atoms. Note that two atoms have been intentionally removed from the array. In (b), the simulated image after white noise has been added. In (c), the resulting image after filtering with an FFT algorithm. In (d), the resulting image after convolution of (b) with a Mexican Hat Wavelet.

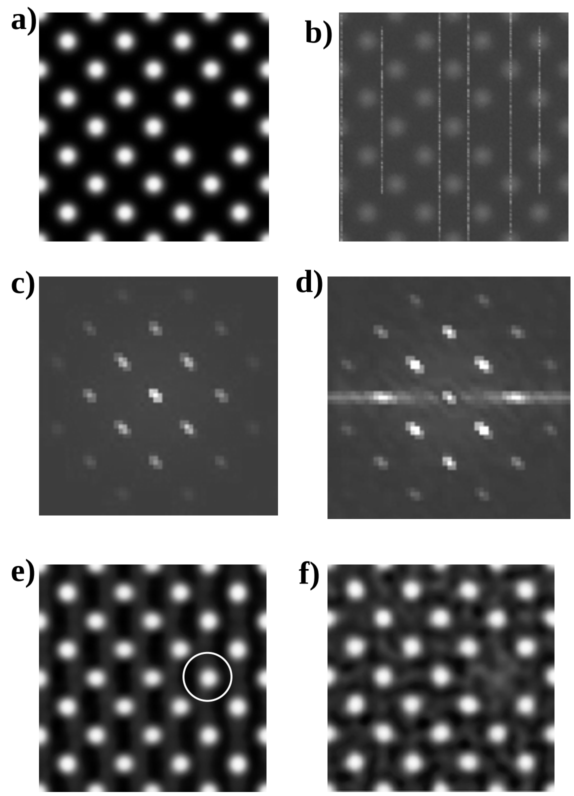

Figure 2: A simulation that includes "scanning tear" noise often encountered in atomic scale studies of SPM images. In (a), a grayscale simulated image of a periodic array of atoms. Note that one atom has been intentionally removed from the array. In (b), the simulated image after "scanning tears" and white noise have been added. The "scanning tears" are artifacts often observed in real SPM images and are related to instabilities of front atoms on the tip. The added noise obscures the periodic array of features. In (c), the result of a FFT of (a) showing well-defined spots which reflect the periodicity of the simulated image. In (d), the result of a FFT of (b). The transform now shows a characteristic streak of noise due to the "scanning tears". This additional noise can obscure those features due to the underlying periodicity of the atoms. An indiscriminate removal of the noise in an effort to filter out the "scanning tears" can lead to an inaccurate image after applying a reverse transform. In (e), the reconstructed images from (d) after intentionally filtering the streak of noise. Note that the scanning tears have been removed but the missing atom in the original image (a) has been inadvertently restored. The atom added by the Fourier transform filtering algorithm is indicated by the white circle. In (f), the wavelet convolved image obtained directly from (b). The wavelet analysis properly reproduces the important features in the original image.