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Nanoparticle Localization Using Gabor Filters

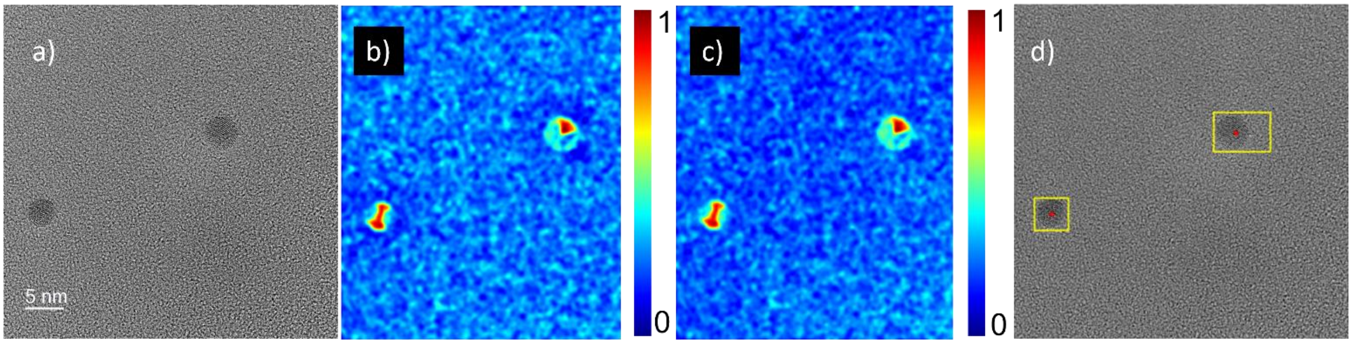
Andrei Hernández-Robles[1], Guillermo Bárcena-González[2], Álvaro Mayoral[3,5], Pedro L. Galindo[2] and Arturo Ponce[1,4*]

[1.] University of Texas at San Antonio, Department of Physics and Astronomy, San Antonio, Texas, United States.
[2.] University of Cádiz, Department of Computer Science and Engineering, Puerto Real, Cádiz, Spain.
[3.] CSIC-University of Zaragoza, Instituto de Nanociencia y Materiales de Aragón (INMA), Zaragoza, Zaragoza, Spain.
[4.] Instituto Nacional de Astrofísica, Óptica y Electrónica, Puebla 72840, México.
[5.] University of Zaragoza, Advanced Microscopy Laboratory (LMA), University of Zaragoza, Zaragoza, Spain.

* Corresponding author: arturo.ponce@utsa.edu

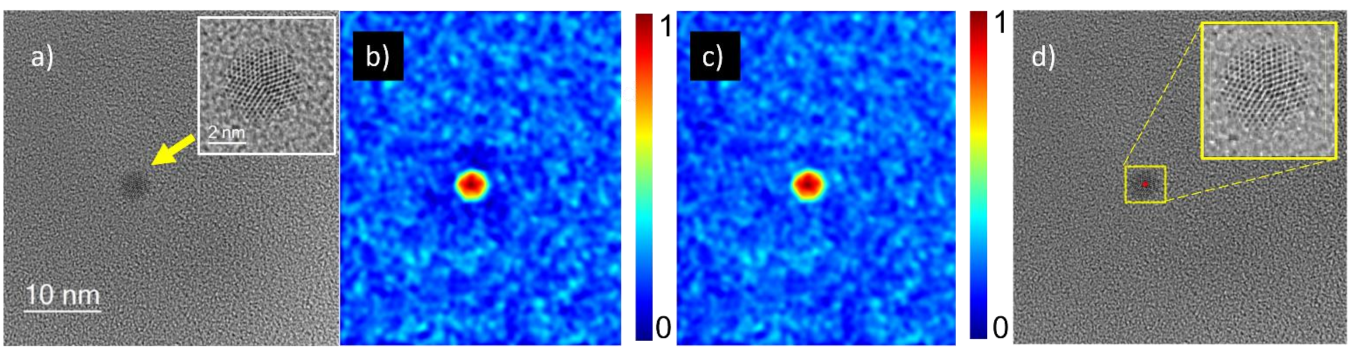
Gabor filters are described as functions product of a Gaussian-shaped kernel and a complex sinusoid function that minimizes the uncertainty principle between the spatial and frequency domains [1, 2]. These filters are specially utilized in computer vision for texture analysis and feature extraction of images, due the nature of the function itself it is possible to extract observations that are well defined and repetitive in the 2D space [3]. For this reason, the high periodicity registered in high resolution transmission electron microscopy (HRTEM) images of crystalline nanoparticles as well as and their shape morphology is highly exploitable. In this work we present a comprehensive method based on Gabor filters to localize in an automatic and efficient manner the nanoparticles, which can be implemented in dynamic studies using in situ transmission electron microscopy (TEM). In this way, orientation, and frequency of appearance of the features observed in the input signal are relevant to analyze the specimen, for instance, planes are rotated around the space occupied by each particle. An important parameter to be considered is the wavelength of the passed filters, which may be determined by the interplanar spacings of the high-resolution images.

In this Algorithm, a Gabor filter bank has been implemented with 36 orientations (between 0 and 180 degrees with a step of 5) and 7 wavelengths (between 4 and 7 pixels with a step of 0.5). Applying this filter-bank to the original image generates consequently a total of 252 Gabor filtered complex images that are added together, in which strong features are located and correlated to the highlighted fringe patterns shown in Fig. 1b. This product is expected to have local variations due to the background, even for zones of constant texture that can affect the localization process of the targets. To determine the background, we apply a Gaussian smoothing kernel with a full width at half maximum (FWHM) of two times the minimum size in pixels of the nanoparticles that we want to detect. This background is then subtracted from the original signal to leave a combination of signal and noise. Later, this signal is smoothed again with a narrower Gaussian of two pixels. By subtracting this smoothed signal and the combination of signal and noise, we obtain an estimation of noise at each pixel [4]. The normalized result can be seen in Fig. 1.c, where the artifacts produced by the background in the original image have been substantially reduced. Different nanoparticles are now easily detectable using a simple threshold equal to a given percentile of the image intensity (i.e. 99%). The latter mentioned can be utilized to determine the position by relating the signal width to the size of the nanoparticles to delimit their range (see Fig. 1 d)). Besides gold nanoparticles in HRTEM, additional carbon film in the background contributes to the noise in these images. These nanoparticles rounded 5 nm in diameter and are shown in Fig. 1 a) and Fig. 2 a). The Fig 1 b-d) sequence shows the workflow for the localization of multiple randomly oriented nanoparticles, where Fig. 1 c) display a fair noise reduction with respect to the previous sub-image, the resultant image encapsulates two nanoparticles in squares of about the particle size. Fig. 2 a) represents a more complex case due the subtle contrast difference between the particle and the amorphous carbon film in the background. Despite that, this film does not produce an intense signal with respect to the strong signal produced by the observations in the particle. Furthermore, the background subtraction performed in Fig. 2 c) is not particularly remarkable. Finally, Fig. 2 d)



represents the correct localization of the nanoparticle [5].

Figure 1. Illustrative sequences of nanoparticle localization algorithm using Gabor filters. a) HRTEM image containing multiple gold nanoparticles randomly oriented. b) sum of the 252 Gabor-filtered images applied. c) background subtraction of image b). d) Localization of the nanoparticles based on the



intensity response in c).

Figure 2. Nanoparticle sequence of a decahedral particle oriented at the five-fold axis. a) HRTEM image containing a single metallic nanoparticle and a noisier background, the inset magnified image displays the target particle indicated by a yellow arrow. b) sum of the 252 Gabor-filtered images applied to the HRTEM image. c) background subtraction of image b). d) Localization of a nanoparticle, the inset image displays a magnification of the localized nanoparticle.

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