Deep-Convolutional-Neural-Network based Method for Improvement of Signal-to-Noise Ratio in Electron Holography

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In the study of reaction mechanisms for chemical catalytic systems, it is important to understand the microscopic structures and chemical properties of the reaction center. Because the catalytic activities are greatly affected by the atomic-scaled structure, the chemical composition, the local charge transfer, and the chemical stabilities, so far the catalytic activities has been improved mainly by modifications of the surface. Ultimately catalysts are considered to have atomically controlled surface such as the metallic nanoparticle with corner atoms replaced by another element [1].

Effects of the surface modifications appear the electric and magnetic fields around the reaction center. Thus the electron holography technique [2] is a powerful tool to investigate the electric and magnetic fields of materials. By using the holography techniques, the magnetic fields of the phase boundaries [3] and the charge transfer in particles [4] have been successfully observed.

However, it is known that the sensitivity for detecting the phase difference is not enough high to obtain the information of catalytic activities. To improve the sensitivity, one of the effective method is noise reduction. The noise is generated in both the measurement and the image processing. Former is an interference process of divided electron waves using biprism, and the latter is an operation of Fourier transformation in the image treatment. Many studies have made great efforts to suppress the noise, for example, by using aberration-correctors [5], multiple acquisition [6] and phase-shift methods [7].

Our idea is an application of deep-convolutional-neural-network (DCNN) [8] to the improvement of the signal-to-noise ratio as shown in Fig. 1. Due to recent progresses of the information technology, the image recognition ability by the DCNN shows the same level as human. Even if the electron hologram with huge number of particles is acquired, DCNN is able to classify these images into preset groups. By calculating average of the huge number of classified images, the signal-to-noise ratio will be improved.

In this work, we applied the DCNN to reduce the noise in the electron holography. As the first experiment, monodispersed spindle-like particles of iron oxides shown in Fig. 2 were used for the target material. The 61 hologram images were obtained by using Hitachi-Hightech HF-3300X with an accelerating voltage of 300 kV. The holograms of the 493 particles were classified into 10 classes we defined in advance. As shown in Fig. 3 the particle image of a class was denoised by averaging 63 images. Our result shows that the signal-to-noise ratio of electron hologram can be improved by averaging method combined with DCNN based classification technique if sufficient number of images is acquired.

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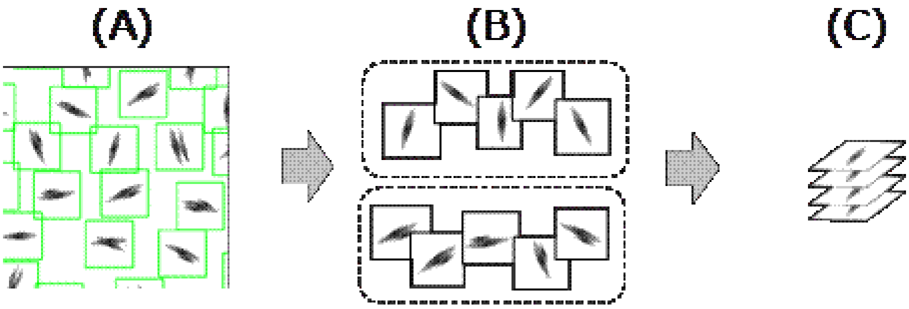

Fig. 1. Procedure of DCNN based signal-to-noise improvement method. (A) Particles are picked up. (B) Images are classified into groups. (C) Averaged image in a class is obtained.

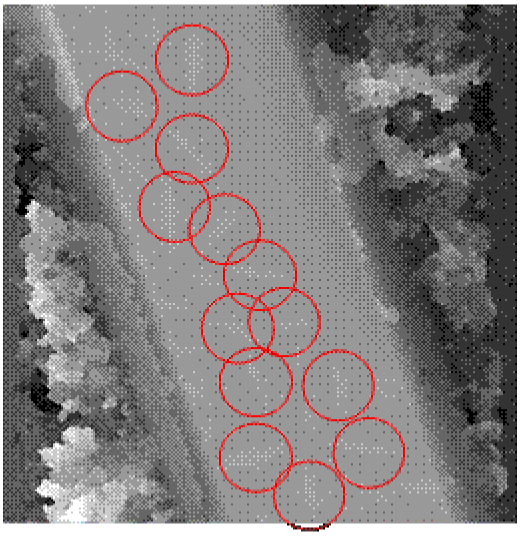

Fig. 2. Electrostatic phase image of spindle-shaped iron oxide particles. The phase image is obtained from electron holography technique. Circles indicate each particle which is picked up for particle classification.

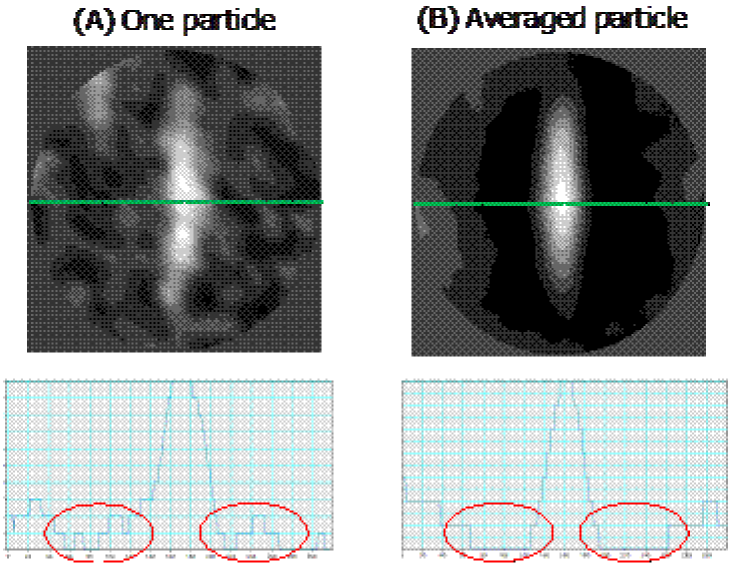

Fig. 3. Images of one particle (A) and averaged particle (B). The averaged image is generated from 63 images of iron oxide particle. The corresponding line profiles are shown below the particle images.