Machine Learning and Spectroscopic Scanning Probe Microscopy: a Magnetoelectric Composite Case Study

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Today Scanning Probe Microscopy (SPM) has evolved from a mere topography analysis tool to a multifaceted functional imaging technique. Recent years have seen a tremendous growth in the so called spectroscopic SPM modes, where spectra of various principle variables like voltage (Piezoresponse/Current), distance (force), frequency (amplitude) etc. are collected over a 2-dimensional grid. However, in certain cases the variable in concern is time dependent, and a point-by-point variation is not ideal. In such cases a convenient alternative is the sequential SPM, where a sequence of SPM images is generated as a function of the principle variable. However, such a method suffers from the absence of a concrete correlation between the consecutive images. In addition to this shortcoming, nature of each individual spectrum may strongly differ with the spatial location. Also, a unique physical model that fits the spectra is not always available *a priori*. Proper application of unsupervised machine-learning to such problems could lead to fast extraction of qualitative components of the spectra, which can conveniently be used to device suitable physical models to fit the data.

Presented in this work is a case study of variable magnetic field Piezoresponse Force Microscopy (PFM) on magnetoelectric composite of $BaTiO_3$-$BaFe_{12}O_{19}$. Such studies are expected to advance the understanding of the stress mediated magnetoelectric phenomenon at local scale. A simple algorithm based on Principal Component Analysis (PCA) was used to extract qualitative magnetic field dependence of the measured piezoresponse. The observed dependence is justified by cross validation with topography images, and by a 3-dimensional visualization of the data.