Application of digital image inpainting in Electrochemical Scanning Probe Microscopy

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Electrochemical scanning probe microscopy is a physical sciences technique that uses a nanoscale physical probe with an electrochemical sensor to map the local chemical activity of interesting substrates, such as carbon nanotubes, graphene and single living cells. These techniques produce measurements of local chemical properties that are unevenly distributed over a surface, then which maps of the local chemical activity can be constructed. Image reconstruction methods, namely PDE-based inpainting, are usually used for restoration of lost or deteriorated parts of photos and videos. We show how to reconstruct local chemical activities using inpainting methods. We compare different techniques, and conclude that heat equation based inpainting suits the purpose best. We also investigate a method to reconstruct the progress of an experiment by applying 3D heat equation inpainting.

I. INTRODUCTION

The acquisition of spatially resolved functional and structural information on surfaces and interfaces is a major theme in contemporary microscopy, with applications spanning materials science [1] and technology [2], biology [3], medicine [4] and nanotechnology [5] generally. To expand the capabilities of microscopy, significant efforts have been invested in the development of scanning probe microscopy (SPM) techniques [6] that facilitate direct measurements of various types of processes at a wide range of interfaces. Scanning probe microscopy (SPM) is a branch of microscopy that forms images of surfaces using a physical probe that scans the specimen. Some probe techniques reach an impressive atomic resolution. Area of our interest is Electrochemical Scanning Probe Microscopy (EC-SPM). It involves the use of a tiny, mobile, probe containing an electrode, which can be used to monitor and/or perturb the chemical environment adjacent to a sample. Typically the probe is scanned laterally over a sample and maps of the local chemical environment are constructed. The data is usually obtained as a two-dimensional grid of data points, visualized in false color as a computer image. During the project we worked with two different techniques: Scanning Ion Conductance Microscopy (SICM) [7] and Scanning Electrochemical Cell Microscopy (SECCM) [8], which, together with overall setup, briefly described in Section II. In SPM tip can be moved across the surface in numbers of different ways: lines, spirals [9]-[12], cycloid [13], Lissajous trajectories [14]. All of them have their advantages and limitations. Some of the scanning modes produce uniformly distributed data, but most of them do not, what impedes imaging. We are looking at different data patterns together with corresponding missing data patterns and trying to restore the complete picture of the experiment using tool from the field of digital inpainting. Digital inpainting is process There are different purpose-dependent types of inpainting, structural (geometric) inpainting, texture synthesis, restoration of videos. We are particular interested in geometric inpainting. Therefore the aim of the project is to reconstruct an image of the whole surface on basis of the available data, thus improve quality of the images of scans using digital inpainting, and develop protocols and code to automatically generate 2D maps and performing 3D inpainting restore the process of the experiment as a set of frames, video. The application of inpainting techniques in microscopy is a new approach which recently started to gain popularity. Ziegler et al. [15] were concerned about the speed of scanning and introduced spiral scanning pattern as a solution to increase scanning rate. They successfully used heat equation inpainting to deal with unevenly spaced data, obtained from Atomic Force Microscopy (AFM) [16] scans. Stanciu et al. [17] ‘experimented with ‘curvature-preserving’ partial differential equations as a solution to inpainting regions in images collected with several optical and scanning probe microscopy techniques’, namely to CSLM, DIC, FRET, AFM, STM, and s-SNOM[17]. Our approach was inspired by Ziegler et al. paper. Here we looked at the application of various PDE-based inpainting algorithms to scans obtained via Scanning Ion Conductance Microscopy (SICM) and Scanning Electrochemical Cell Microscopy (SECCM) techniques (described below), considered utilization for different scanning patterns, i.e hopping mode scans, line scans and spiral scans. We compared the performance of different inpainting methods, such as Laplace equation-based approach, algorithms proposed by Bertalmio et al. [18] and Perona-Malik [19], on experimental data and chose the most suitable for practical purposes. In the next

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In section II we describe methods we used to collect, preprocess the data, and to inpaint regions left empty after redistributing information to the grid. In section III we present results, obtained after processing experimental data; compare performance of different inpainting techniques on SICM and SECCM (described in Section II) scans with different scanning patterns and grid sizes, and explore their limitations. After we move on to conclusions and discussion of further work.

II. METHODS

In this section we describe methods we used for data acquisition, reduction and preprocessing, filtering and inpainting.

A. Data acquisition

We worked with two types of EC-SPM, namely SECCM and SICM.

Scanning ion conductance microscopy (SICM) is a scanning probe technique, which utilizes a nanopipette to scan samples bathed in electrolytic solution. The operation of SICM relies on an ion current that flows between an electrode inside a nanopipette and another electrode in an external bath solution. This ion current, which is highly dependent on the tip-sample separation, is utilized as a feedback signal to maintain the tip-sample separation and to allow the pipette to follow surface contours, which generates topographic information [7].

Scanning electrochemical cell microscopy (SECCM) is a new pipette-based imaging technique purposely designed to allow simultaneous electrochemical, conductance, and topographical mapping of surfaces. SECCM uses a tiny meniscus or droplet, at the end of a double-barreled (theta) pipette, for high-resolution nanoscale electrochemical measurements [8].

1. Experimental setup

Here we briefly describe the experimental setup for the scanning techniques used to obtain the data (see Figures 1, 2).

On the Figure 1 we can see configuration of probe, piezoelectric positioners and sample. Probe ((1) in Figure 1) is fixed in the probe holder ((4) in Figure 1) and connected to z piezoelectric positioner, which controls vertical movement towards or away from the surface of the tip during the scan. Sample ((2) in Figure 1) and sample holder ((3) in Figure 1) are located on x-y piezoelectric positioners ((5) in Figure 1) for lateral motion of the sample relative to the nanopipette.

Figure 2 represents overview of the whole setup. The amplifiers/servos ((10) in Figure 2) are responsible for piezoelectric positioners. A bipotentiostat ((12) in Figure 2) measures electrochemical signals at the probe. An FPGA card ((13) in Figure 2) collects all the data and controls the instrument. The use of an FPGA card allows complex calculations, such as data filtering and probe position control logic, to be completed quickly. LabVIEW is used ((14) in Figure 2) to control the FPGA card on the PC.

Electrical, acoustic and vibrational isolation are essential for high resolution current measurements and positional control. All instruments are mounted on vibration isolation tables ((8) in Figure 2), within a Faraday cage, and with acoustic foam to reduce vibrations ((9) in Figure 2) [20].

2. Scanning modes

Images of a surface are constructed in 3 different modes: hopping mode, line scanning, spiral scanning.

In the hopping mode ((a) in Figure 3), the probe approaches the surface at a predetermined x,y position and collects data. After that the tip retreats from the sample surface to move to the next point. This makes a
FIG. 3: (a) Hopping mode; (b) Line scan; (c) Spiral scan.

series of evenly-spaced discrete measurements providing a lattice with uniformly distributed data, which allows construction of a 2D map. This mode is the slowest one of the three described in this section, because we have to stop the scanner many times when moving between points. The advantage is that since data is evenly spaced it does not require redistribution on a grid. In order to speed up the scanning process or scan larger areas we can make sparse measurements and use inpainting as a tool to reconstruct the image (see Section III).

In the line scanning mode ((b) in Figure 3) maps of the surface properties are constructed from a series of parallel lines scans. The probe is moved forward and then back over the same line, before being moved laterally to the start of the next line. Data is collected during both the forward and reverse movements, therefore two maps (a forward and a reverse map) of the surface properties can be constructed from every scan. Since the line scanning mode has a so-called ‘fast scan direction’ with many measurements on a line and a ‘slow scan direction’ with quite a few lines, data is distributed unevenly and there are gaps in the ‘slow scan direction’. Inpainting can fill the gaps to create smooth maps.

Spiral techniques are common to many data storage techniques on spinning mediums (vinyl records, hard drives, compact disks and DVDs). However the spiral scan concept only recently found appearance in scanning probe microscopy, where spirals [9-12], cycloid [13], Lissajous trajectories [14], and various other scan patterns have been demonstrated. Spiral scanning has been shown to be useful for fast scanning, because they do not require to stop the tip at any time and cover wider areas in the same time, comparable to other patterns [9-12]. As it is obvious from the name, during spiral scans, the tip is moved over the surface spirally, x,y positioners follow the system of parametric equations for Archimedean spiral with constant speed:

\[ x = \alpha \sqrt{t} \sin(\beta \sqrt{t}) \]
\[ y = \alpha \sqrt{t} \cos(\beta \sqrt{t}) \]

Acquired data is unevenly spaced and to construct a 2D map the process of rendering to a grid and inpainting become crucial.

B. Data description and preprocessing

LabVIEW code was used for management of the experiment process and data collection. As a result we get two files: one with a description of the experiment parameters and how the data is stored (in .set format), and the actual results (in .tsv format). The latter consists of rows of time series of the following variables: x,y,z coordinates, tip current, surface current, voltage, line number and other unused variables. We wish to construct 2D maps, which show the current (tip or surface depending on experiment) distribution on xy plane. In order to bring the data to a usable form we need to do some preprocessing. We use MATLAB for the implementation of all the algorithms described below.

1. Data reduction

Data measurements are taken continuously during an experiment, even if it is paused, therefore multiple measurements at the same point in space can occur. First, these measurements are averaged, what also reduces size of the data. An optional step, for line scans, is to only use information from the forward scan. This is not necessary because the regridding algorithm (described below) deals with a mismatch between forward and backward scans or unevenly spaced data.

2. Filtering

Even with number of measures taken to minimize interference during the experiment (electrical, acoustic and vibrational isolation), there is still noise present in the data. In order to reduce noise we use digital filtering. Even though data represents the dependency between current and a point in space, considering how measurements were taken, we treat it as a time series and apply 1D Gaussian low pass filtering [21]. The Gaussian filter modifies the input signal by convolution with a Gaussian function,

\[ f(x) = \exp\left( -\frac{x^2}{2\sigma^2} \right), \]

where standard deviation \( \sigma \) and kernel \( x \) size depend on the experiment.

3. Regridding

To redistribute the non-gridded data ((a) in Figure 4) back to the grid of the desired image we use linear binomial interpolation. The height information for each data point is spread to the four nearest points on the grid ((b) in Figure 4). Furthermore, we attribute a weighting factor to each point (shown in subsection C), which describes
FIG. 4: (a) Non-gridded position sensor data with the color of each square representing height values. (b) To distribute the non-gridded data to the grid, the height information of each data point is spread to the four nearest neighbors. Close proximity of the data point to the pixel position leads to higher weights shown as size of the squares. Original data positions shown as dotted squares. (c) Heat equation inpainting diffuses the existing weighted data out to the entire grid filling empty data points while denoising. (d) Final rendered image. Reproduced from [15].

the confidence of the data, and is given by the distance from the data point to the grid. When only one data point contributes to the pixel the height value is simply copied and the weighting saved for use in the inpainting algorithm. When more than one data point contributes to the same pixel, the weights are used to linearly interpolate height information from the contributing data points to determine the value and a composite weighting value is saved for the inpainting algorithm ((c), (d) in Figure 4). Hence, for large data sets and coarse grids, this first step might be sufficient to attribute a value to each pixel and thereby generate a full image. However pixels might remain empty when sparse data sets are projected on a fine grid. In this case, inpainting must be applied [15].

C. Inpainting

The digital inpainting process can be looked upon as a linear or non-linear transformation, where $I_0$ is the original image and $I$ is the transformed image (i.e. the digitally inpainted image). The image processor can be looked upon as a function $f$ as follows:

$$f : I_0 \rightarrow I$$

Let $\Omega$ denote the set of pixels of the image $I$ to be inpainted; this can be also called a mask. Let $\partial \Omega$ denote the one pixel wide boundary of $\Omega$ (see Figure 5). Digital inpainting regarding 3D objects resembles digital inpainting of 2D images. Geometric partial differential equations (PDEs) are used to inpaint surface holes. However, instead of only working in two dimensions, the geometric PDEs may be used to inpaint surface holes in $n$ dimensions [22], [23].

1. Linear interpolation

The easiest way to fill the region to be inpainted is to use a similar method to the regridding described above, i.e. linearly interpolate available information using inverse distance weighting, not being bounded by just four nearest neighbors, but by a suitable radius $R$ or the boundary of the image. The mask is filled in the following way:

$$Y = \frac{\sum_I (X/D^p)}{\sum_I (1/D^p)}$$

where $D$ is the distance (in pixels) from the mask node $Y \in \Omega$ to nodes outside the mask $X \in \bar{\Omega}$, all or within radius $R$, and $p$ is a positive real number, called the power parameter. Greater values of $p$ assign greater influence to values closest to the interpolated point. Values inside $\Omega$ farther from $\partial \Omega$ will tend toward the average of all the values.

2. Heat equation inpainting

This algorithm is in widespread use [24]. We are using the Laplace equation, which is the steady-state heat equation in 2 and 3 dimensions respectively:

- $\frac{\partial^2 \Omega}{\partial x^2} + \frac{\partial^2 \Omega}{\partial y^2} = 0$

- $\frac{\partial^2 \Omega}{\partial x^2} + \frac{\partial^2 \Omega}{\partial y^2} + \frac{\partial^2 \Omega}{\partial z^2} = 0$

FIG. 5: The image $I$, the region $\Omega$ to be inpainted and its boundary $\partial \Omega$
To reconstruct the image we solve this equation on Ω with Dirichlet boundary conditions ∂Ω. To do so, we discretize the PDE using finite differences for the partial derivatives. In other words, we replace any node in the grid inside Ω by the average of its four neighbors. We then solve obtained linear system, which is typically well conditioned, via LU decomposition.

3. Bertalmio inpainting

Bertalmio et al. [18] pioneered a digital image inpainting algorithm based on partial differential equations (PDEs). A user-provided mask specifies the portions of the input image to be retouched and the algorithm treats the input image as three separate channels (R, G and B). For each channel, it fills in the areas to be inpainted by propagating information from the outside of the masked region along level lines (isophotes). Isophote directions are obtained by computing at each pixel along the inpainting contour a discretized gradient vector (it gives the direction of largest spatial change) and by rotating the resulting vector by 90 degrees. This intends to propagate information while preserving edges. A 2-D Laplacian is used to locally estimate the variation in color smoothness and such variation is propagated along the isophote direction. After every few steps of the inpainting process, the algorithm runs a number of diffusion iterations to smooth the inpainted region. Anisotropic diffusion is used in order to preserve boundaries across the inpainted region. Steady state is achieved if the smoothness of the image (its second derivative) is constant along the isophotes. The assumption of constant smoothness along isophotes is in general not justified. Since edges are continued straightly into the inpainting domain, round objects tend to develop straight segments meeting at acute angles, thus producing kinks and neglecting the principle of continuation of direction.

Inpainting is viewed as an iterative process with the following evolution equation, which runs only inside the region to be inpainted:

\[
I_{n+1}^i = I_n^i + \Delta t I_t^n(i, j), \forall (i, j) \in \Omega,
\]

where \( n \) is the current iteration, \((i, j)\) are pixel coordinates, \( \Delta t \) is the rate of improvement.

\[
I_t^n(i, j) = |\partial L^n(i, j)| \cdot N^n(i, j),
\]

where \( |\partial L^n(i, j)| \) is the measure of the change in the information \( L^n(i, j), N^n(i, j) \) is the direction of propagation, chosen to be isophote direction \( \nabla I(i, j) \). The steady state is achieved, when \( I_t^n(i, j) = 0 \). The discrete scheme is the following:

\[
I_t^n(i, j) = (|\partial L^n(i, j)| \cdot N^n(i, j)) \cdot |\nabla I^n(i, j)|,
\]

\[
\partial L^n(i, j) := (L^n(i+1, j) - L^n(i-1, j), L^n(i, j+1) - L^n(i, j-1))
\]

\[
L^n(i, j) = I_{xx}(i, j) + I_{yy}(i, j)
\]

\[
\frac{\bar{N}^n(i, j)}{|\bar{N}^n(i, j)|} = \frac{(-I_{xx}^n(i, j), I_{yx}^n(i, j))}{\sqrt{(I_{xx}^n(i, j))^2 + (I_{yx}^n(i, j))^2}}
\]

\[
\beta^n(i, j) = \frac{\partial L^n(i, j)}{|\partial L^n(i, j)|} \cdot \frac{\bar{N}^n(i, j)}{|\bar{N}^n(i, j)|},
\]

and

\[
|\nabla I^n(i, j)| = \begin{cases}
\sqrt{(I_{xwm}^n)^2 + (I_{nym}^n)^2 + (I_{xym}^n)^2 + (I_{ynm}^n)^2}, & \text{when } \beta^n > 0 \\
\sqrt{(I_{xwm}^n)^2 + (I_{ym}^n)^2 + (I_{xym}^n)^2 + (I_{ynm}^n)^2}, & \text{when } \beta^n < 0
\end{cases}
\]

4. Anisotropic diffusion inpainting

The implementation of discrete anisotropic diffusion is based on the formulas shown in Perona and Malik’s literature [19]. The underlying equation is the following:

\[
I_t = \text{div}(c(x, y, t) \nabla I) = c(x, y, t) \Delta I + \nabla c \cdot \nabla I,
\]

where \( c(x, y, t) = g(||\nabla I(x, y, t)||) \). This equation can be discretized on a square lattice in the following way, with a 4-nearest-neighbors discretization of the Laplacian operator:

\[
I_{i,j}^{n+1} = I_{i,j}^n + \lambda [c_N \cdot \nabla N_I + c_S \cdot \nabla S_I + c_E \cdot \nabla E_I + c_W \cdot \nabla W_I]_{i,j}^n,
\]

where \( n \) is the current iteration, with \( 0 \leq \lambda \leq 1/4 \) for the numerical scheme to be stable.

\[
\begin{align*}
\nabla_N I_{i,j} & \equiv I_{i-1,j} - I_{i,j} \\
\nabla_S I_{i,j} & \equiv I_{i+1,j} - I_{i,j} \\
\nabla_E I_{i,j} & \equiv I_{i,j+1} - I_{i,j} \\
\nabla_W I_{i,j} & \equiv I_{i,j-1} - I_{i,j}
\end{align*}
\]

\[
e_{X,i,j}^n = g(||\nabla X I_{i,j}||),
\]

where \( X = N, S, E, W \) and \( g(\nabla I) = e^{-\frac{(||\nabla I ||^2)}{K^2}} \) or \( g(\nabla I) = \frac{1}{1 + (\frac{||\nabla I ||}{K})^2} \). The first option for \( g \) privileges high-contrast edges over low-contrast ones, whereas the second privileges wide regions over smaller ones [19].
III. RESULTS

In this section, we apply and compare the techniques described in the previous section and choose the most suitable one for the aim of the project.

A. Experiment in hopping mode

Here we test different image reconstruction methods on data obtained from the experiment in the hopping mode, as described in previous section. In Figure 6 we see a SICM (see Section I) scan of polystyrene (partial film with holes) on a glass. The map reflects relative phase of the ion current which corresponds to surface charge. The original image ((a) in Figure 6) was corrupted ((b) in Figure 6) to create the effect of sparse measurements. This allows a comparison between the original image and the different inpainting methods introduced in Section II ((c)-(f) in Figure 6).

All schemes produce a good approximation of the initial image, considering that about 50 percent of the data was removed, and we can clearly distinguish the border of the hole in the polystyrene. In this case, heat equation based inpainting gives the best result: it produces the image closest to original (in terms of least-squared error). The reason for this might be due to the relationship between the heat equation and the underlying diffusion processes during the experiment which is described by Fick’s law of diffusion [25]. It is also more practical when compared with the Bertalmio et. al. algorithm and the Perona-Malik algorithm, because the equation doesn’t have a time term, i.e. does not need to take multiple steps to converge, therefore it works faster; and unlike the former two algorithms it does not have parameters on which its performance strongly depends. Bertalmio et. al. algorithm showed itself to be numerically unstable as Bertalmio et. al. discussed [18]. The outcome of this experiment gives us an opportunity to speed up the scanning process and to cover a wider area by making sparse measurements in hopping mode and then restoring the rest of the image.

B. Experiment in line scanning mode

Figure 7 shows data from the experiment using SECCM (see Section II) in line scanning mode: pattern in which the tip makes dense measurements in the X direction, but leaves large gaps in the Y direction (see Section II). This scan is of a single-wall carbon nanotube [26],[27]. Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. The map shows the growth of tip current where the reaction occurs between tip and nanotube, in contrast with an inert substrate. In Figure 7 we see the original image (a), on which all 20 lines stack together without any explicit interpolation, and results of linear interpolation (b), Bertalmio et al. inpainting (c), anisotropic diffusion based algorithm (d) and several heat equation inpainting images (f), (h), (j). In this case linear interpolation does not give any benefit when compared to the original image. The Bertalmio et al. algorithm reveals difficulties in tuning parameters and does not produce a smooth result. The anisotropic diffusion and heat equation algorithms work comparatively well, but the heat equation algorithm is preferable due to its advantages in speed and simplicity. Figure 7 (c)-(j) shows results for various grid sizes, i.e. different gaps between lines in slow scan direction. Grid size 200×80 gives good results, whereas grid size 200×120 shows artifacts of the inpainting process, therefore limitations in choice of grid size are always case-dependent. Overall each method has difficulties in preserving sharp/smooth edges across large gaps, which is still one of the main research directions for

FIG. 6: (a) Original image; (b) Corrupted image; (c) Inverse distance weighting inpainting; (d) Heat equation inpainting; (e) Bertalmio inpainting; (f) Perona - Malik inpainting.
the field of inpainting [28].

C. Experiment in spiral scanning mode

In the experiment using SICM (see Section II), fast spiral scans are used to detect deposition of Platinum nanoparticles on HOPG (Highly Ordered Pyrolytic Graphite). Figure 8 shows Field Emission Scanning Electron Microscopy (FESEM), discussed in [29], scan of this surface.

Platinum oxidizes hydrazine, which changes the local conductivity. This process can be detected using SICM. Use of an Archimedean spiral results in a slight rotation in the scan direction. Red color on Figure 9 (a)-(f) represents the highest intensity of tip current, defining the region with Platinum nanoparticles.

Figure 9 (a), (c), (e) shows images of experimental data redistributed on square grids of size 400, 800, 1200 respectively. Figure 9 (b), (d), (f) shows images reconstructed using heat equation. Note that, inpainting diffuses data to the edges of the square grid circumscribing the collected data and the pixels outside the scan region do not accurately depict sample properties. Heat equation restoration gives impressive results for different grid sizes in this case.

D. 3D inpainting

Dynamic evolution of surface processes can be observed using a combination of the fast scanning technique and inpainting in 3 dimensions. This is the same experiment as for the SICM spiral scan detecting platinum nanoparticles from the previous subsection, however we are now looking at the experiment as a process rather than just one spiral. The experiment consists of a series of spiral scans with the voltage growing linearly, which allows us to see variation in reaction rate and finally, when voltage is high enough, to detect platinum nanoparticles. Thus, one spiral represents the experiment at different voltage values, in other words, one map does not represent the surface at one constant voltage value. But it is possible, using digital inpainting in 3D, to reconstruct the progress of the experiment as a video, where each frame is a surface at one constant voltage value. For this purpose, methods B and C from Section II should be extended to the 3D case. Data reduction and filtering are done in the same way, as data acquired as time series. Speaking of regridding, we divide each spiral into 10 parts, which will become 10 frames, assuming that voltage is constant at each piece, and then redistribute each part to a 2D grid. This was dictated by limitations of computational power and memory, but it is possible to create an analogue in 3D for the 2D regridding algorithm from Section II. The result, which depends on the size of the grid, is expected to be similar.

To fill large gaps on each frame we solve the heat equa-
We investigated the scope for the application of digital inpainting to the field of Electrochemical Scanning Probe Microscopy imaging. We examined different PDE-based image restoration methods on images collected by several electrochemical scanning probe microscopy techniques and chose the most suitable one. We found this to be heat equation inpainting, based on accuracy and overall performance, high speed and absence of parameters. Protocols and code were developed to automatically generate 2D maps. Along with the advantages and the good quality results provided by the tested method, we have noted the limitations of this technique. The quality of the results depends on choosing an optimal value for the grid size. We also note that the ability to preserve edges over large gaps is another constraint and needs to be improved through further work. Overall, our experiments show that inpainting techniques can represent a solution in several scenarios common for microscopy imaging, such as the presence of artifacts, and acquisition impossibility for particular sample regions. This approach will facilitate further work in the area of microscopy imaging.

V. CONCLUSIONS

We investigated the scope for the application of digital inpainting to the field of Electrochemical Scanning Probe Microscopy imaging. We examined different PDE-based image restoration methods on images collected by several electrochemical scanning probe microscopy techniques and chose the most suitable one. We found this to be heat equation inpainting, based on accuracy and overall performance, high speed and absence of parameters. Protocols and code were developed to automatically generate 2D maps. Along with the advantages and the good quality results provided by the tested method, we have noted the limitations of this technique. The quality of the results depends on choosing an optimal value for the grid size. We also note that the ability to preserve edges over large gaps is another constraint and needs to be improved through further work. Overall, our experiments show that inpainting techniques can represent a solution in several scenarios common for microscopy imaging, such as the presence of artifacts, and acquisition impossibility for particular sample regions. This approach will facilitate further work in the area of microscopy imaging.

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VI. SUPPORTING MATERIALS

Results of 3D inpainting are available to download from the following links in .gif format:
- a) Before inpainting
  https://www.dropbox.com/s/r3saagpo3b9ez9/3dNaN200.gif
- b) After inpainting
  https://www.dropbox.com/s/0v8igfdaes3689n/3dinp.gif
VII. REFERENCES


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