The Natural Materials Browser: Using a Tablet Interface for Exploring Volumetric Materials Science Datasets

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Abstract

We present a novel tablet application, the *Natural Materials Browser*, that allows a user to interact with volumetric datasets created from a series of natural materials samples. The data samples – high resolution meso-scale volumetric images of nutshells gathered via micro-computed tomography – are envisioned as "virtual specimens" presented many orders of magnitude larger than their characteristic length scale. The user, initially placed in the center of the volumetric dataset and facing orthogonally toward the original 2D image slices, uses an iPad tablet as a magic lens to view and navigate the data via physical rotation and multitouch gestures. The user has simultaneous access to multiple representations of the datasets from any angle or position, and an additional viewport provides real-time, spatial statistics on the current view of the currently loaded dataset. We conducted a preliminary evaluation of the application by collating cognitive walkthroughs given to domain experts in materials science. Their feedback indicated that our tablet application could potentially be an effective tool for enabling insights regarding these data samples and, more generally, that it functions as a low-cost, immersive system with which to explore volumetric datasets.

Index Terms: I.3.6 [Computer Graphics]: Methodologies and Techniques—interaction techniques

1 Introduction & Related Work

In materials science, the development of new materials with enhanced performance requires a detailed understanding of the internal structure of existing materials to connect the causal relationships between structure and property. Some researchers are interested in discovering how the organization of the internal structure, or microstructure, of natural materials lead to their enhanced structural properties and, subsequently, how to artificially recreate these same conditions. Materials have complex 3D structures and with emerging characterization techniques (e.g. atomic probe microstructure, micro computed tomography, serial sectioning) materials scientists are capable of producing detailed volumetric datasets from a breadth of materials systems. Visualizing the 3D structure of materials is complicated due to the wide array of material features (e.g. composition, orientation) whose 3D arrangement directly effects the materials performance. Even in the case of binary phase materials, the topology of the material is rich and complex, as indicated in the data used for this study. These example datasets are generated by micro-computed tomography (micro-CT) of various nutshells – pecan, hazelnut, coconut, and macadamia – with salient phases that are pore and solid. Micro-CT produces voxel-based 3D data with each voxel being described as phase zero or one, pore or solid, respectively. By visualizing the complex pore structure of natural materials, materials scientists hope to understand the source of their exceptional structural properties via both the raw data and subsequent statistical analysis.

Our prototype tablet application, the *Natural Materials Browser*, aids the materials scientist in the preliminary analysis of volumetric datasets and offers the following benefits: it is low-cost and easy to deploy; it allows the user to view the data from arbitrary angles and positions; it provides multiple visualizations of the volumetric samples; it couples real-time statistics with the visualizations; and it provides a sense of immersion within the data. The *Natural Materials Browser* aims to augment the existing workflow of the materials scientist by providing an easy way to discover structural and statistical properties of material samples. By integrating existing visualization and interaction techniques, our application effectively provides insight about volumetric datasets to materials scientists that would otherwise only be noticed through more extensive investigation.

The main viewport of the application acts as a window that displays a portion of the currently loaded sample. Rotating the tablet updates the view in real-time, and provides a new perspective of the data from a different angle, created via interpolating between the original 2D image slices of micro-CT data. Additional viewports simultaneously provide further information regarding the current view and the sample as a whole, including: a geometrical interpretation created using a mesh of an isosurface of the scalar data, a view of the data using a GPU raycasting technique, and a statistical representation of the data (using autocorrelation). An interactive legend situates the user by highlighting the user's location within the volumetric data. The user can swipe the screen to load in another microstructure dataset, encouraging the user to make comparisons between the different materials. Figure 2 shows a screen capture of the tablet application with the statistics viewport, the interactive legend, and the raycasting visualization visible along the bottom part the screen. In our prototype, the user can select either an isosurface visualization or a raycasting visualization (in the lower right hand viewport of the application).

Figure 1: A user changes his vantage point of the currently loaded dataset by physically rotating inside the virtual space.

A number of visualization techniques exist to aid in reasoning about volumetric data. More general solutions for visualizing material data samples are discussed in [6]. Material science datasets can be visualized with desktop software packages or frameworks others. For instance, [7] describes an "image-to-simulation" framework that makes use of multiple visualization techniques to enhance

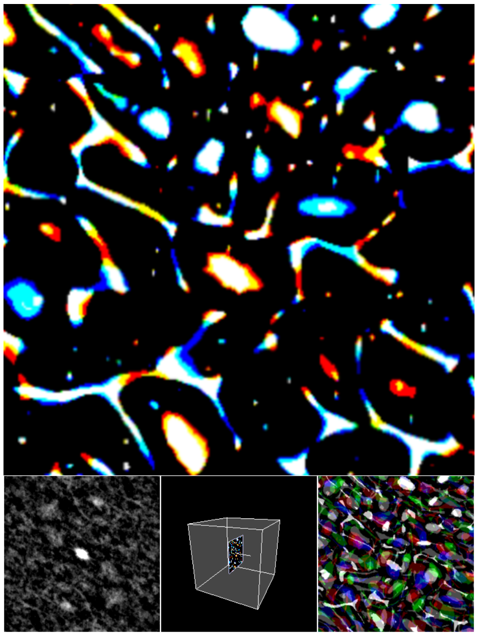

Figure 2: A screen capture of the Natural Materials Browser.

and validate models describing the structure of porous rock. However, in practice the most common methods of preliminary analysis within the materials science community usually involve viewing the raw data as a series of discrete image slices and generating statistical plots for each slice, often independently of each other. The main issue with this approach is that the data sample is only viewed from a single direction and decontextualized from the full dataset. Furthermore, the visual inspection of the data is often decoupled from the statistical analysis of the data. Using the gyroscope and multitouch sensors on the tablet computer, we simulate the movement of the user through the volumetric dataset. Although there is conflicting evidence in the literature regarding the importance of accurately tracking motion for effective immersion (cf. [4, 5]), a recent paper concludes that "allowing for full-body rotations without actual walking can provide considerable performance benefits, even for complex and cognitively demanding navigation tasks" [3]. Magic lens interfaces are frequently used in volume visualization tasks. For instance, [2] describes an application that uses a magic lens interface as a virtual "flashlight," highlighting fiber tracts in volumetric medical imagery. Another recent paper compares mouse interaction with gesture-based magic lens interaction and finds that magic lens interaction outperforms mouse interaction in time and accuracy for orientation matching tasks [1]. Our application provides a low-cost mechanism that helps users build an effective mental model of the 3D dataset. Figure 1 shows an example of a user navigating the virtual volume using the iPad.

2 Preliminary Evaluation

As a preliminary evaluation, we ran cognitive walkthroughs with ten domain scientists. These domain scientists included five professors at three different universities and five post-docs at two different universities. The easy-to-deploy nature of our browser greatly helped the evaluation process and accessibility across different institutions. Since these scientists regularly examine and conduct statistical analyses of volumetric data, we wanted to solicit their feedback on the application while they performed various preliminary data analysis tasks, such as identifying interesting aspects of the materials and deciding whether or not the samples warranted more detailed investigation. We were mainly interested in determining the potential value of introducing the application as another element within the workflow of a materials scientist, rather than in the detailed measuring of the individual effectiveness of particular techniques. Each of the domain experts indicated that they found the *Natural Materials Browser* to be a promising tool for investigating materials data. They were particularly intrigued by the idea of easily viewing volumetric data at arbitrary viewing angles. Overall, they also found the simultaneous viewports to be valuable in communicating the idea of correlation when seen directly alongside the corresponding interpolated view of the raw data. Similarly, the users became clearly aware of some qualitative features of the data from the statistics, such as the preferential orientation of pores when the material is looked at in different viewing planes. That is, simply by rotating the iPad around the virtual specimen, properties of the data were displayed that otherwise would have only been noticed with more extensive analysis. Some subjects questioned the value of the raycasting and isosurfaces visualizations and were initially confused by the color mapping. At the same time, some of the subjects recognized the potential usefulness of incorporating additional viewport modules. In our sessions we also discussed issues of ergonomics, such as the potential for fatigue that might occur from full-body rotations during extended use of the application and whether or not it was awkward to use one hand to hold the tablet while the other hand was interacting with or pinching the tablet. Since we envision this tool as a "browser" – a first pass that provides enhanced initial information about the statistics and anisotropy to indicate intriguing aspects of the materials data – we expect that the materials scientists will not necessarily use the tablet for a long period of time, but rather take the information they have gathered from our application to conduct further analysis on a more powerful workstation.

While the initial feedback from domain scientists is encouraging, further work on evaluating the efficacy of the immersive aspects of the application needs to be carried out. In particular, we plan to carry out a more rigorous comparison with an implementation that does not require physical rotation (e.g., rotating the data using a mouse or virtual trackball). Furthermore, we would like to extend the modularity of the application so that a wider range of visualization and analysis techniques could be selected as needed for particular datasets.

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