New modeling approach transforms imaging technologies

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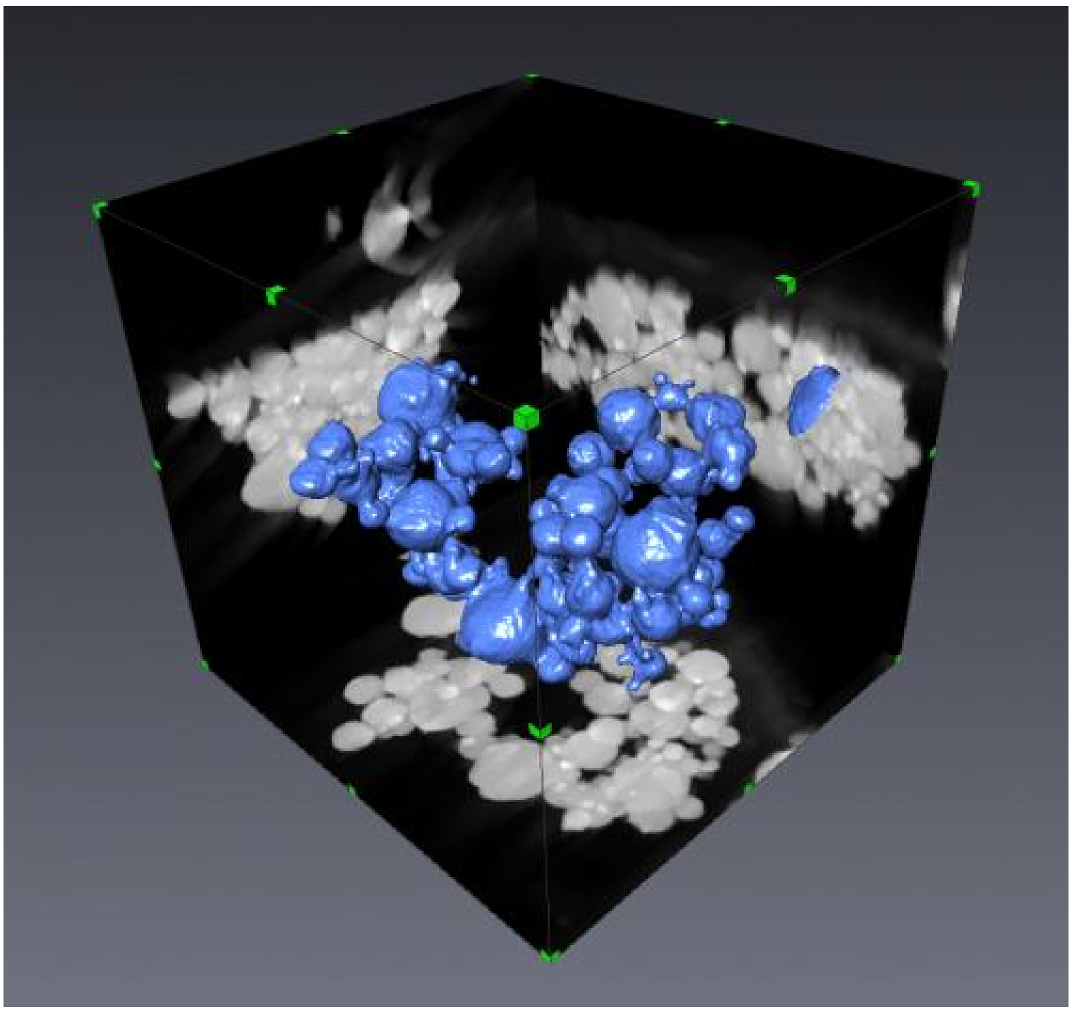

Researchers are improving the performance of technologies ranging from medical CT scanners to digital cameras using a system of models to extract specific information from huge collections of data and then reconstructing images like a jigsaw puzzle. Here, the method is used to create a high-resolution 3-D electron microscopy reconstruction of aluminum nanoparticles, aiding efforts to design nanocomposites for applications ranging from fuel cells to transparent coatings. Credit: Purdue University

Researchers are improving the performance of technologies ranging from medical CT scanners to digital cameras using a system of models to extract specific information from huge collections of data and then reconstructing images like a jigsaw puzzle.

The new approach is called model-based iterative reconstruction, or MBIR.

"It's more-or-less how humans solve problems by trial and error, assessing probability and discarding extraneous information," said Charles Bouman, Purdue University's Michael and Katherine Birck Professor of Electrical and Computer Engineering and a professor of biomedical engineering.

MBIR has been used in a new CT scanning technology that exposes patients to one-fourth the radiation of conventional CT scanners. In consumer electronics, a new camera has been introduced that allows the user to focus the picture after it has been taken.

"These innovations are the result of 20 years of research globally to develop iterative reconstruction," Bouman said. "We are just scratching the surface. As the research community builds more accurate models, we can extract more information to get better results."

In medical CT scanners, the reduction of radiation exposure is due to increased efficiency achieved via the models and algorithms. MBIR reduces "noise" in the data, providing greater clarity that allows the radiologist or radiological technician to scan the patient at a lower dosage, Bouman said.

"It's like having night-vision goggles," he said. "They enable you to see in very low light, just as MBIR allows you to take high-quality CT scans with a low-power X-ray source."

Researchers also have used the approach to improve the quality of images taken with an electron microscope. New findings are detailed in a research paper being presented during the Electronic Imaging 2013 conference in San Francisco this week.

Traditionally, imaging sensors and software are designed to detect and measure a particular property. The new approach does the inverse, collecting huge quantities of data and later culling specific information from this pool of information using specialized models and algorithms.

"We abandon the idea of purity – collecting precisely what we need," Bouman said. "Instead, let's take all the measurements we possibly can and then later extract what we want. This increases the envelope of what you can do enormously."

Purdue, the University of Notre Dame and GE Healthcare used MBIR to create Veo, a new CT scanning technology that enables physicians to diagnose patients with high-clarity images at previously unattainable low radiation dose levels. The technology has been shown to reduce radiation exposure by 78 percent.

"If you can get diagnostically usable scans at such low dosages this opens up the potential to do large-scale screening for things like lung cancer," Bouman said. "You open up entirely new clinical applications because the dosage is so low."

A CT scanner is far better at diagnosing disease than planar X-rays because it provides a three-dimensional picture of the tissue. However, conventional CT scanners emit too much radiation to merit wider diagnostic use.

"But as the dosage goes down, the risk-benefit tradeoff for screening will become much more favorable," Bouman said. "For electron microscopy, the principle advantage is higher resolutions, but there is also some advantage in reduction of electron dosage, which can damage the sample."

The research to develop Veo has been a team effort with Ken Sauer, an associate professor of electrical engineering at Notre Dame, in collaboration with Jean-Baptiste Thibault, Jiang Hsieh and Zhou Yu. Thibault and Yu worked on the technology as graduate assistants under Bouman and Sauer and both currently work for GE Healthcare.

"And, there are lots of other people doing similar and related research at other universities and research labs around the world," Bouman said. "Ultimately, 3-D X-ray CT images might require little more dosage than old-fashion planar chest X-rays. This would allow CT to be used for medical screening without significant adverse effects."

In the electron microscope research, MBIR was used to take images of tiny beads called aluminum nanoparticles.

"We are getting reconstruction quality that's dramatically better than was possible before, and we think we can improve it even further," Bouman said.

Improved resolution could help researchers design the next generation of nanocomposites for applications such as fuel cells and transparent coatings.

The paper was authored by Purdue doctoral student Singanallur Venkatakrishnan; U.S. Air Force Research Laboratory researchers Lawrence Drummy and Jeff Simmons; Michael Jackson, a researcher from BlueQuartz Software; Carnegie Mellon University researcher Marc De Graef; and Bouman. A tutorial article also appeared in January in the journal *Current Radiological Reports*.

The models and algorithms in MBIR apply probability computations to extract the correct information, much as people use logical assumptions to draw conclusions.

"You search all possible data to find what you are looking for," Bouman said. "This is how people solve problems. You saw Bob yesterday at the store; you wonder where he was coming from. Well, you determine that he was probably coming from work because you have some probabilistic models in your mind. You know he probably wasn't coming from San Francisco because Bob doesn't go to San Francisco very often, etc."

MBIR also could bring more affordable CT scanners for airport screening. In conventional scanners, an X-ray source rotates at high speed around a chamber, capturing cross section images of luggage placed inside the chamber. However, MBIR could enable the machines to be simplified by eliminating the need for the rotating mechanism.

Future research includes work to use iterative reconstruction to study materials. Purdue is part of a new Multi-University Research Initiative funded by the U.S. Air Force and led by De Graef. Researchers will use the method to study the structure of materials, work that could lead to development of next-generation materials.

More information: Electronic Imaging 2013: spie.org/electronic-imaging.xml

Model Based Iterative Reconstruction for Bright Field Electron Tomography, Singanallur V. Venkatakrishnan a, Lawrence F. Drummy b, Marc De Graef c, Jeff P. Simmons b, and Charles A. Bouman a a Purdue University; b Air Force Research Lab; c Carnegie Mellon University

ABSTRACT
Bright Field (BF) electron tomography (ET) has been widely used in the life sciences to characterize biological specimens in 3-D. While BF-ET is the dominant modality in the life sciences, it has been generally avoided in the physical sciences due to anomalous measurements in the data due to a phenomenon called "Bragg scatter" - visible when crystalline samples are imaged. These measurements cause undesirable artifacts in the reconstruction when the typical algorithms such as Filtered Back Projection (FBP) and Simultaneous Iterative Reconstruction Technique (SIRT) are applied to the data. Model based iterative reconstruction (MBIR) provides a powerful framework for tomographic reconstruction that incorporates a model for data acquisition, noise in the measurement and a model for the object to obtain reconstructions that are qualitatively superior and quantitatively accurate. In this paper we present a novel MBIR algorithm for BF-ET which accounts for the presence of anomalous measurements from Bragg scatter in the data during the iterative reconstruction. Our method accounts for the anomalies by formulating the reconstruction as minimizing a cost function which rejects measurements that deviate significantly from the typical Beer's law model widely assumed for BF-ET. Results on simulated as well as real data show that our method can dramatically improve the reconstructions compared to FBP and MBIR without anomaly rejection, suppressing the artifacts due to the Bragg anomalies.

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