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PREPROCESSING OF ION MICROTOMOGRAPHY DATA FOR IMPROVED RECONSTRUCTION QUALITY

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ABSTRACT

In Ion Microtomography (IMT), material densities are determined from the energy lost by ions as they pass through a specimen. For fine-scale measurements with micron-size beams, mechanical stability and precision of motion can impact the quality of the reconstruction. We describe several preprocessing procedures used to minimize imperfect specimen manipulation, including adjustment of the center of mass motion in sinograms and correction for vertical translations. In addition, the amount of noise in the reconstruction is reduced by utilizing median (as opposed to mean) ion energy loss values for density determinations. Furthermore, particular portions of the sampled image can be enhanced with minimal degradation of spatial resolution by a judicial choice of spatial filter in the reconstruction algorithm. The benefits and limitations of these preprocessing techniques are discussed.

INTRODUCTION

Ion Microtomography (IMT), unlike x-ray computed tomography methods, measures the energy lost by each ion rather than the fraction of the radiation absorbed [1,2]. A number of residual ion energies, typically 5 to 100 are measured for each sampled point. The incident ion energy is chosen to ensure the primary source of energy loss is due to interactions with specimen electrons and the charged ion. The mean or median value of the energy loss distribution is used as the energy loss value of the sampled point. The energy loss is then converted to a density value using tabulated electronic stopping powers[3]. A single projection is made by scanning the beam across the specimen, or translating the specimen through the beam for larger specimens. After each projection the specimen is rotated slightly to prepare for a new projection. Projections are acquired until the specimen has been rotated through 180 or 360 degrees. The density data are then reconstructed using a filtered backprojection technique. Multiple reconstructed slices may then be combined to form a 3-dimensional density image of the specimen.

A number of parameters can affect the ultimate resolution in the reconstructed density image. In this paper, we describe methods to preprocess the IMT data in order to improve the image quality. One parameter influencing the reconstruction is acquiring erroneous data due to ion damage in the detector. We describe changes made in the energy loss-to-density conversion code to help correct this problem. As beam sizes decrease, the accuracy and precision of the specimen movement system become important. Small scale perturbations in positioning alter the results so preprocessing adjustments must be made in the data. Another parameter is using the median, rather than the mean, residual ion energy to compute the line integrated density. We consider the trade-offs of using the median to eliminate spurious data but at the price of greater calculation times to evaluate. We also discuss the effects of using different filters with the reconstruction algorithm. Edge definition enhancement and density gradients are sensitive to the particular filter implemented.

PREPROCESSING TECHNIQUES TO CORRECT FOR MOTION ERRORS

With improvement in focusing ion beams to smaller sizes and the accompanying increase in image resolution, staging instabilities which could once have been safely ignored begin to have a large impact on reconstruction quality. Figure 1 shows tomographic data taken with a 0.25 micron proton beam of a 25 micron diameter glass pipette at the Micro Analytical Research Centre (MARC) of the University of Melbourne. Two hundred fifty-six contiguous slices were made of this pipette. To our knowledge, this is currently the highest resolution ion beam tomogram.

There were, however, a number of problems with this data which required preprocessing. The top row of images in Figure 1 shows several of the raw sinograms from the 256 slices. Each projection is made up of 256 rays with a projection taken every degree over 180 degrees. The effect of 1 to 5 micron bearing wobble in the manipulator rotation is seen along the edges of the sinograms. The second row of images display the reconstructions of the raw sinograms. Because of the bearing wobble effect, the reconstruction code could not correctly reconstruct the data about any one center of rotation. The third row of the figure shows the sinograms after making center of mass corrections[4]. In the image the center of mass of each projection has been shifted to a position equivalent to having the pipette perfectly aligned at the manipulator's center of rotation. The fourth row of images are the reconstructions of the corrected sinograms. As resolution increases this technique or similar techniques which preserve correct spot spacing will become more important in acquiring and presenting useful data.

MEDIAN VS MEAN ENERGY LOSS VALUES FOR DENSITY DETERMINATION

The transmitted ion energy loss at each sampled point can be calculated with either a mean or median value The mean value is faster computationally since the processing can be done as each ion is detected. On the other hand, calculation of the median value is more time consuming, but is less sensitive to extraneous data points[5]. Fig. 2 shows reconstructed images of a silicon pillars specimen using different numbers of ions and either the mean or median value from the residual energy distributions. As can be seen in the figure the median produces a less noisy image. The improvement in image quality using the measured median energy loss greatly outweighs its additional computational expense even in large data sets.

ION DETECTOR CALIBRATION

IMT measurements are also conducted at the Sandia Microbeam Analysis Laboratory in Livermore (SMALL)[1] collaboratively with the Lawrence Multi-user Tandem Laboratory[6]. Our data acquisition system utilizes a silicon surface barrier detector to measure residual ion energy. The detector is subject to damage from the ions depending upon their energy and fluence. We raster the detector to reduce the exposure time that the beam hits any given spot. The damage causes a shift in the measured energy and thus produces erroneous values in the IMT data file. In early reconstructions, the detector calibration was determined with only one energy value. The associated sinograms reflected this shift in energy due to the detector damage. To account for this, the energy loss-to-density conversion code was modified to calculate individual detector calibrations for each row of IMT data. Fig. 3 shows sinograms of a silicon specimen using 100 protons per sampled spot. The first image shows the sinogram using one value for the calibration. The second shows the same sinogram when a separate calibration is computed for each projection. The third image is their difference. The reconstruction average density increases by 0.08% with the modified version of the code and the image noise decreases by 1.6% in standard deviation.

SPATIAL FILTERS

The choice of filter used with the backprojection algorithm can also affect the final reconstructed image[7]. Figure 4 shows four reconstructions of the silicon pillar data. Each is reconstructed from a data set made with 100 protons per spot using median data. The top two images are filtered with a Hamming filter, the bottom two use a 6^{th} order Butterworth approximation for a ramp filter. The Hamming filter tends to accentuate the lower frequencies in the reconstruction, and is used for enhancing density gradients in the specimen. The Butterworth filter amplifies the higher frequency components. This type of filter is used in edge definition studies or for examining machined surfaces. It is very important that the experimenter is aware of the variations a filter selection will make to his reconstruction. It is quite possible to hide or smear the exact feature of interest if an improper filter selection is made.

SUMMARY

The improvement in resolution of IMT systems has brought about problems related to specimen manipulation and detector damage caused by the resolution related increase in sampling time. This paper has described preprocessing techniques developed by the authors to solve these problems.

ACKNOWLEDGEMENTS

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REFERENCES

1. A. E. Pontau, A. J. Antolak, D. H. Morse, A. A. Ver Berkmoes, J. M. Brase, D. W. Heikkinen, H. E. Martz and I. D. Proctor, Nuc. Inst. Meth. B40.41 (1989) 646.
2. A. E. Pontau, A. J. Antolak, D. H. Morse, Nuc. Inst. Meth. B(1990) in press.
3. F. Ziegler, Handbook of Stopping Cross-sections for Energetic Ions in all Elements.Pergamon Press, New York, 1980.
4. S. G. Azevedo, D. J. Schneberk, J. P. Fitch, H. E. Martz, LLNL Report UCRL-102615, IEEE Trans. Nuc. Sci., Vol.37, #4 (Aug. 90), 1525-1540.
5. J. C. Overly, R. M. S. Schofield, J. D. MacDonald, and H. W. Lefevre, Nucl. Inst. Meth. B30 (1988) 337.
6. I. D. Proctor, J. C. Davis, M. R. Eaton, J. I. Garibaldi, T. L. Moore, B. J. Schumacher, J. R. Southon, and T. A. Zimmerman, Nucl. Inst. Meth. A268 (1988) 344.
7. D. J. Schneberk, H. E. Martz, S. G. Azevedo, M. Skeate, LLNL Report UCRL-101264, (1989), and The American Society for Nondestructive Testing Topical Conference on Industrial Computerized Tomography Topical Proceedings, July 25-27, Seattle, WA, Am.Soc.for NDT, Columbus OH (1989)609.

FIGURE CAPTIONS

Figure 1 Sinograms and reconstructed images of a 25 micron pipette. This data was acquired at the Micro Analytical Research Centre (MARC) of the University of Melbourne. Row one contains three raw pipette sinograms displaying 1 to 5 micron bearing wobble along the edges. Row two displays reconstructions of these sinograms. In row three the center-of-mass of each projection has been aligned to the center of rotation of the rotary manipulator. The reconstructions of the corrected sinograms are displayed in row 4.

Figure 2 Reconstructed images of a silicon specimen using different numbers of ions and either the mean or median value of the residual energy loss distribution.

Figure 3 This figure displays the effect of ion damage to a silicon surface barrier detector. The first image displays a sinogram of a silicon specimen acquired using 100 ions and the median value of the residual energy loss distribution when one value is chosen to calibrate the detector. The second image shows the same sinogram when a separate calibration is computed for each projection. The final image is their difference.

Figure 4 The top row displays reconstructed images of a silicon specimen filtered using a Hamming filter at two different cutoff frequencies. The bottom row displays the same data reconstructed using Butterworth 6th order filters at cutoffs corresponding to those of the top row.

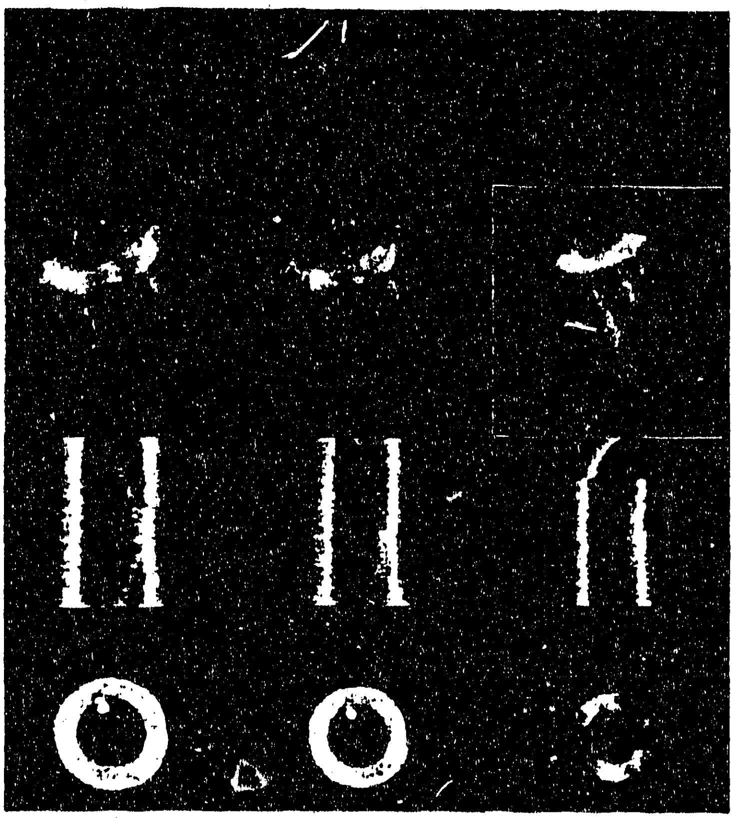

Figure 1.

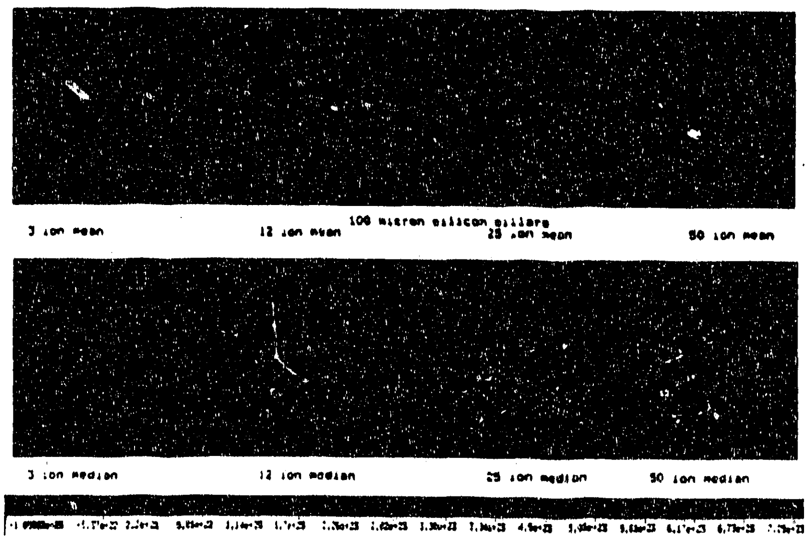

Figure 2.

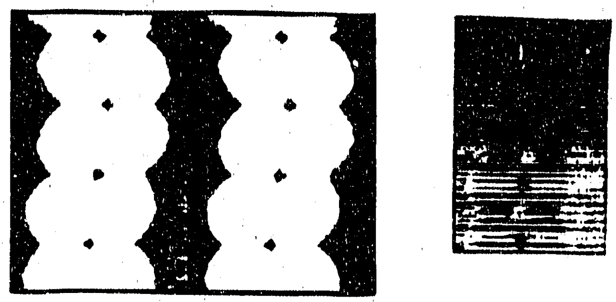

Figure 3.

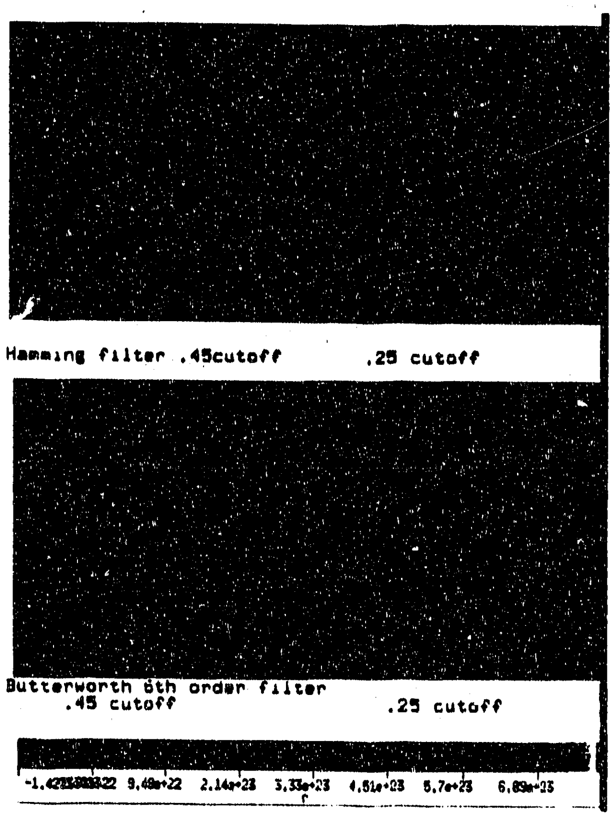

Figure 4.

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