Investigation Of Multi-Resolution Support For MeV Ion Microscopy Imaging

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Abstract. To minimize the dose applied to the specimens during imaging in a MeV ion microbeam we have investigated new concepts that allow collection of images with multi-resolution support. To test the concept, a set of reference PIXE microbeam images with well-characterised noise were segmented using both a direct down-sampling technique and wavelet decomposition. The results show both techniques could be used to select fields of view with <2% of the fluence required to collect a normal image, however, there is no compelling reason to select one technique over the other.

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INTRODUCTION

Over the past 20 years, or so, wavelet-based image processing has attracted considerable attention. Images of natural objects such as images produced by ion microbeams are made up of features on a range of size scales. Image analysis using wavelets is based on image decomposition into a hierarchal tree of sub-images. These techniques facilitate image-analysis and manipulation on different scales simultaneously. Filter banks and down-sampling are used to give a multi-resolution representation with localisation in both spatial and frequency domains[1]. Wavelet approaches are powerful tools for image de-noising while preserving edge information and discontinuities, cryptography, image merging and "invisible" watermarking[1]. The industry-standard JPEG2000 image compression standard[1,2] uses a wavelet-based coding and decoding to facilitate both lossless and lossy compression that can allow progressive decoding of an image with progressively improving fidelity[1,3].

From an image-processing viewpoint an ion microprobe can be considered to be an instrument that sequentially samples an analogue image (2D-sample) by probing with an ion beam and quantises the information received (detector - data acquisition) to produce a digital image. The counting of quanta gives a linear mid-tread[1] quantisation (e.g. a Particle Induced X-ray Emission (PIXE) intensity map). Unlike normal images, such as a photographs and X-ray shadowgraphs, ion microprobe images are generally speckled. The intensity is generally Poisson distributed[4] where the probability p of detecting n quanta per pixel is $p(n) = \lambda^n ne^{-\lambda} / n!$. The mean number of counts λ give the variance, $\lambda = \sigma^2$. When λ is small, there is a significant probability, $p(0) \xrightarrow{\lambda \to 0} 1 - \lambda$ that there are no counts in a pixel. The significance of the zero-count pixels is that they carry no information and we cannot differentiate between pixels corresponding to zero intensity in the image function and zero counts from Poissonian noise[5]. The rapid transition over one pixel width from white to black implies the high-frequency information in these speckled images is significant.

The objective of this work was to investigate if a multi-resolution supported imaging strategy can be used to reduce the fluences needed for rapidly finding the field of view when using ion microprobes. This is particularly important when imaging biomedical

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specimens, where low–fluence techniques[6,7] are necessary to avoid detrimental ion induced changes in the specimen[8]. The work was motivated by the development of a new MeV ion microbeam (DREAM[9]) at the Pelletron accelerator in Jyväskylä that will feature high speed post-focus scanning coupled with a new generation of data collection system that is based on time-stamping to facilitate on-the-fly image transformation in lateral as well as time dimensions.

BASIS OF THE METHOD

The underlying idea is based on the different reaction of the human visual system to low- and high-frequency information in an image. For localisation of fields of interest it is generally sufficient to present only the low frequency information. The approach used is very akin to the classic filter-bank used to decompose images signals in wavelet analysis[1,3]. Fig. 1 a) illustrates the wavelet decomposition filter bank.

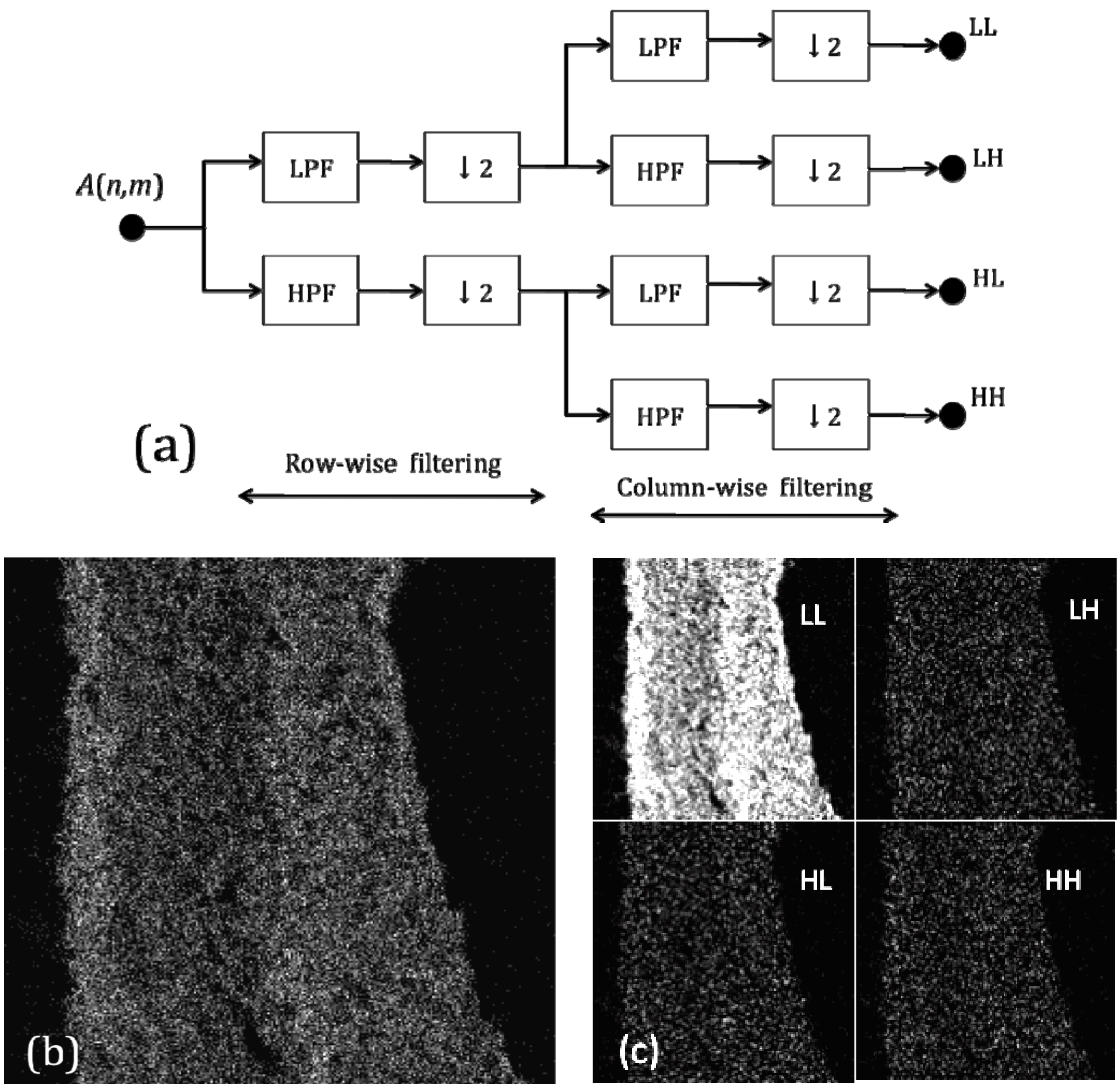

FIGURE 1. (a) Filter bank for wavelet decomposition. The input image *A(n,m)* is fed to a set of low-pass (LPF) and high-pass filters (HPF) followed by a down-sampling step. The filters act first row–wise and then column-wise to decompose the image into different bands LL, LH, HL and HH in the horizontal and vertical directions. (b) K Kα image *A*(*n,m*) (see text) used as input to the filter bank. The size of the field is 1100 ×1100 µm (c) decomposed images from the wavelet filter bank. (The images have been adjusted to give optimal printed contrast).

Fig. 1 b) is the ion microbeam image. Fig 1 c) the first level decomposition. It is seen the LL band image is a lower resolution image of the original image, where the low-frequency information is preserved. The high-frequency information in LH, HL and HH (Fig. 1 (c)) can be used for de-noising and signal compression[1,3]. Unlike normal wavelet decimation, which takes place in one shot, we decimate the image on-the-fly to concentrate the counts into a series of lower resolution images. In this way, zero pixels associated with Poissonian noise are suppressed making the image easier to visually interpret.

EXPERIMENTAL

A PIXE image of K Kα X-rays from a thin section of a rabbit aorta measured using 2 MeV protons measured at the National University of Singapore was used as a test. The image was chosen as it represents a typical natural image with a region of pixels with zero counts and an area with fairly, but not completely, uniform distribution of K. In the uniform contrast region, the counts per pixel were close to Poisson distributed over more than three decades with a mean of 1.85, a maximum of 7 counts per pixel, and ~33% of pixels had zero counts.

A data file was generated of *x* and *y* pixel coordinate pairs for each K Kα X-ray photon that makes up the image. By randomising the pixel coordinate pair sequence in the file, images corresponding to different number of detected photons (i.e. ion fluence) could be simulated by reading the corresponding number of pixel coordinates.

The procedure to form multi-resolution images is as follows:

- A series of 256×256 pixel images containing 1000, 4000, 16000 and 64000 counts were created.
- The wavelet decomposition was calculated using the Daubechies db4 wavelet[3,10] and the set of different resolution images extracted from the decomposition vector[3]. To overcome artefacts associated with boundary distortions[3], symmetric boundaries with half-point boundary values were used.
- The extra pixels associated with periodic boundaries[3] were trimmed from the images.
- The contrast of each image was expanded to fill a 256-level greyscale.

The possibility of improving the 1000 count 32×32 pixel approximation image using wavelet de-noising was carried out by selecting the threshold settings[3] on a cut-and-try basis. The decimation by direct down-sampling was carried directly by re-binning counts into pixels according to the decomposition level.

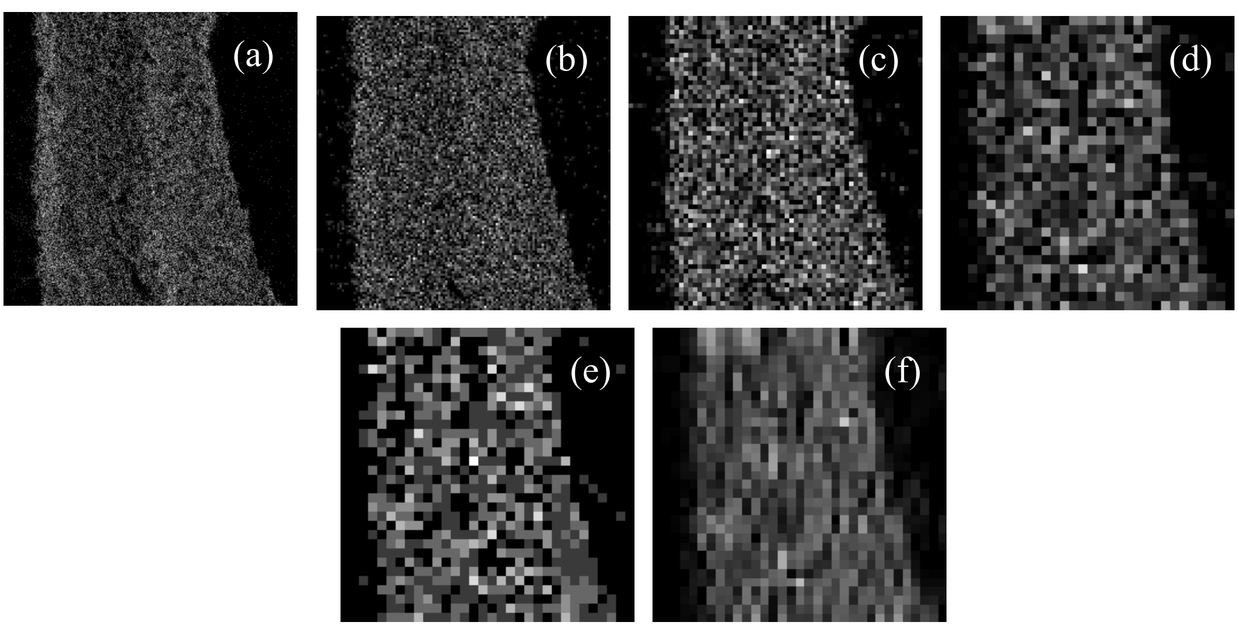

FIGURE 2. Multi-resolution representation of the image data using Daubechies wavelet db4. a) 64000 counts in full resolution 256×256 pixel image with field size 1100 ×1100 μm. (b) 16000 counts in 128×128 pixel level-1 image approximation. (c) 4000 counts in 64×64 pixel level-2 image approximation. (d) 1000 counts in 32×32 pixel level-3 image approximation. (e) 1000 counts in direct down-sampled 32×32 pixel image. (f) De-noised image of (d) using a soft threshold set at 0 and 12 for Level 1 and 2 wavelet coefficients, respectively. (The images have been adjusted to give optimal printed contrast.)

RESULTS AND DISCUSSION

Fig. 2 (a-d) presents the contrast expanded and level-3, level-2, level-1 and level-0 (full resolution) wavelet decomposed images for 1000, 4000, 16000 and 64000 counts, respectively. Comparison of Fig. 2 (a) and (d) reveals that even for 1000 counts (<2% of the fluence required for the full resolution image) the salient (low frequency) image components required for location of regions of interest are well reproduced. Comparison of the wavelet-decimated and direct down-sampled images (Fig. 2 (d) and (e)) shows they are very similar, but not identical. The difference can presumably be associated with choice of wavelet[3,10]. Whereas direct down sampling is inherently lossy, wavelet decimation is loss-less. The extra information in the decomposition vectors of the latter can be used for de-noising. Figure.2 (f) shows such wavelet de-noising smoothes the image in Fig 2 (d) and removes outlying non-zero pixels. The processing time for the wavelet decomposition and filtering using a 2.33 GHz dual core processor is less than 100 ms. The method above can hence be carried out on-the-fly to give processed and de-noised images in real time.

Use of the multi-resolution support for locating fields of interest requires that at each level the fluence is uniform over the field of view. This is not well-suited where conventional slow magnetic[11] or mechanical rastering of the beam is used. To facilitate straightforward multi-resolution support in DREAM[9], a fast electrostatic beam scanning system is being constructed that when used in conjunction with time-stamped data collection will facilitate different scan modes by reading pixel coordinates from a sequence file.

A further interesting possibility is to use the pattern writing capabilities of modern microprobes to collect images with different resolutions in different regions of the image in order to minimise the fluence in high resolution images. This would find application in imaging of low confluences of cells on a substrate. Rendering of region-dependent resolution images is already implemented in the JPEG2000 standard[1,2].

CONCLUSIONS

It is shown that by using wavelet decomposition or direct mean-filtering combined with down-sampling techniques to create multi-resolution ion microbeam images, low-fluence scans suitable for locating fields of interest can be obtained with about 2% of the fluence required for a normal quality image. The reduced resolution image quality can be further visually improved by de-noising using a wavelet method. There is no clear advantage of one technique over the other.

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REFERENCES

1. S. Jayaraman, S. Esakkiajan and T. Veerakumar, in *Digital Image Processing* (Tata McGraw Hill Education Private Ltd., New Delhi, 2009)
2. *JPEG Image Coding System, JPEG 2000 Final Committee Draft V. 1.0, 16 March 2000*, M. Bolick (ed.)
3. M. Misiti, Y. Misiti, G. Openheim, J. M. Poggi, *Wavelet Toolbox 4, Users guide* (Mathworks, 2010) http://www.mathworks.com/access/helpdesk/help/pdf_doc/wavelet/wavelet_ug.pdf
4. P. Sigmund, *Particle penetration and Radiation Effects*, Springer, Hiedelberg, 2006, pp. 380-382.
5. I. Rodrigues, J. Sanches, J. Bioucas-Dias, *Denoising of medical images corrupted by Poisson noise*, Proc. IEEE Int. Conf. on Image Processing ICIP 2008, (IEEE, 2008) 1756, DOI: 10.1109/ICIP.2008.4712115
6. M. Ren, H. J. Whitlow, A. Sagari A. R., J. A. van Kan, T. Osipowicz and F. Watt, *J .Appl. Phys*. **103**, 014902 (2008).
7. H. J. Whitlow, M. Ren, J. A. van Kan, T. Osipowicz and F. Watt , *Nucl. Instr. and Meth. B* **267**, 2149 (2009)
8. F. Watt, P. S. P. Thong, A. H. M. Tan, S. M. Tang, *Nucl. Instr. and Meth. B* **130,** 216 (1997)
9. R. Norarat, et al., *Nucl. Instr. and Meth. B* (In submission).
10. I. Duabechies, *Ten lectures on wavelets*, CBMS-NSF Regional Conf. Series in Applied Mathematics, SIAM (1992).
11. G. W. Grime and F. Watt, *Beam Optics of Quadrupole Probe-Forming Systems*, (Adam Hilger, Bristol, 1984) pp. 111.