Super-Resolution X-ray Imaging with Hybrid Pixel Detectors

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Introduction

Super-resolution describes a method estimating a single high-resolution image from several slightly shifted low-resolution images.

Using hybrid pixel detectors together with a micro-focus X-ray source allows to significantly reduce the required post-processing of high-resolution images. Since such detectors are almost noise-free and the magnified X-ray spot is smaller than a single pixel, the *point spread function* (PSF) of the imaging system can be neglected. Thus, the resulting images typically do not require further processing [1].

Therefore, this approach is interesting for imaging with pixel detectors, since such detectors have a limited amount of pixels at high cost.

Interpolation methods

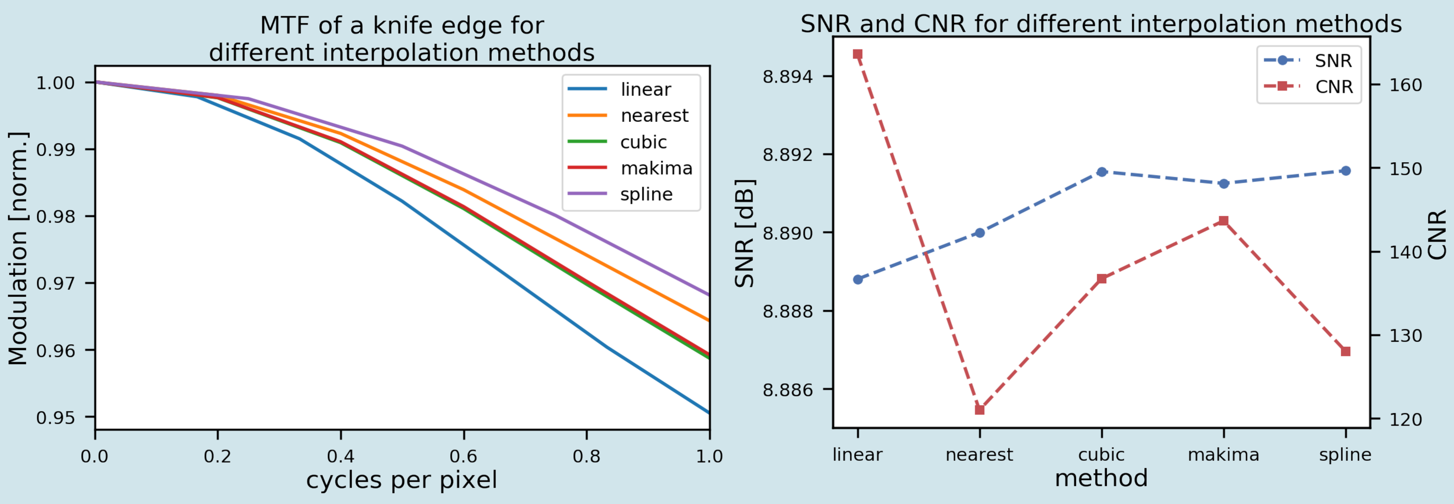

Fig. 1 Different interpolation methods (*linear*, *nearest neighbour*, *cubic*, *makima*, *spline*)

Comparing interpolation methods shows that *spline* provides the best edge quality and the highest signal to noise ratio. Moreover, *cubic* and *makima* interpolation perform slightly worse on edge quality, but provide higher contrast to noise ratios.

Upscaling factor and amount of images

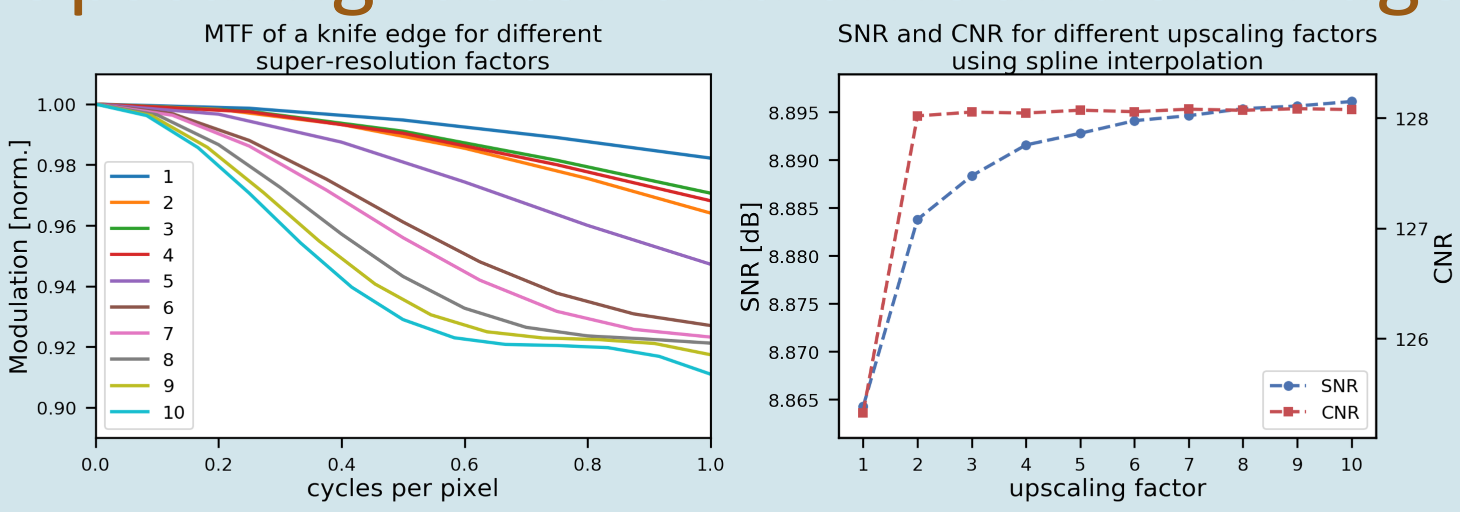

Fig. 2 Different interpolation factors using a 4x4 grid and a sample translation of 3 pixels

Using 4x4 images shows that upscaling factors between 2-4 provide the best results in terms of sharp features. The CNR is almost unaffected by the upscaling factor, while the SNR increases, except when using *nearest neighbour* interpolation.

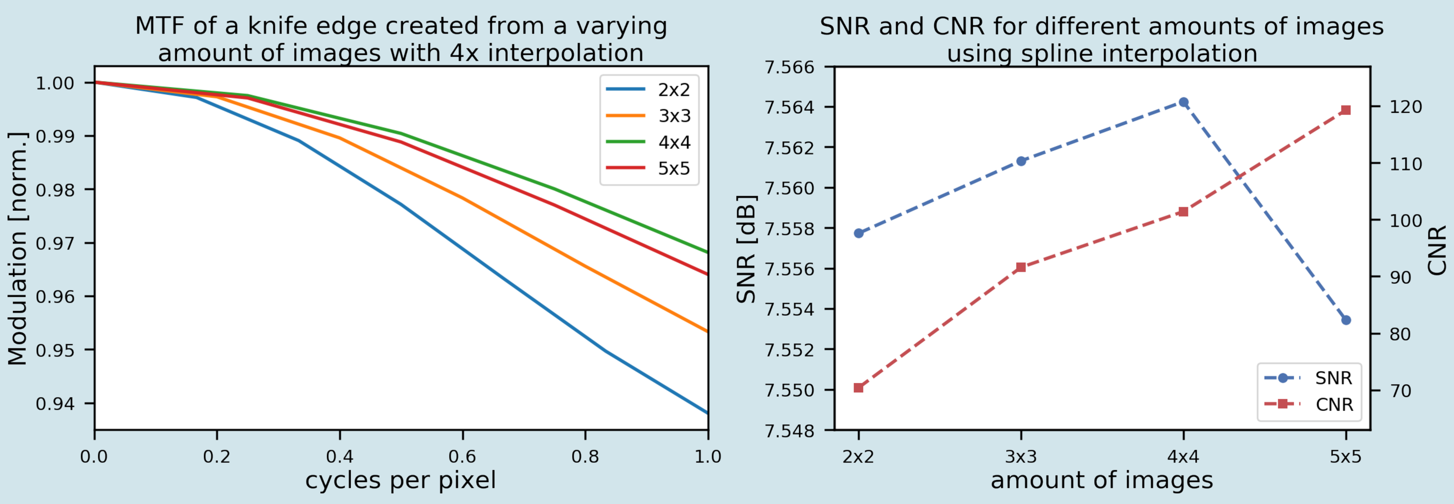

Fig. 3 4-times interpolation applied to a varying amount of images

Considering an upscaling factor of 4 with 4x4 images provides the best result for sharp edges and also the best SNR. The CNR increases with the amount of images.

Image translation

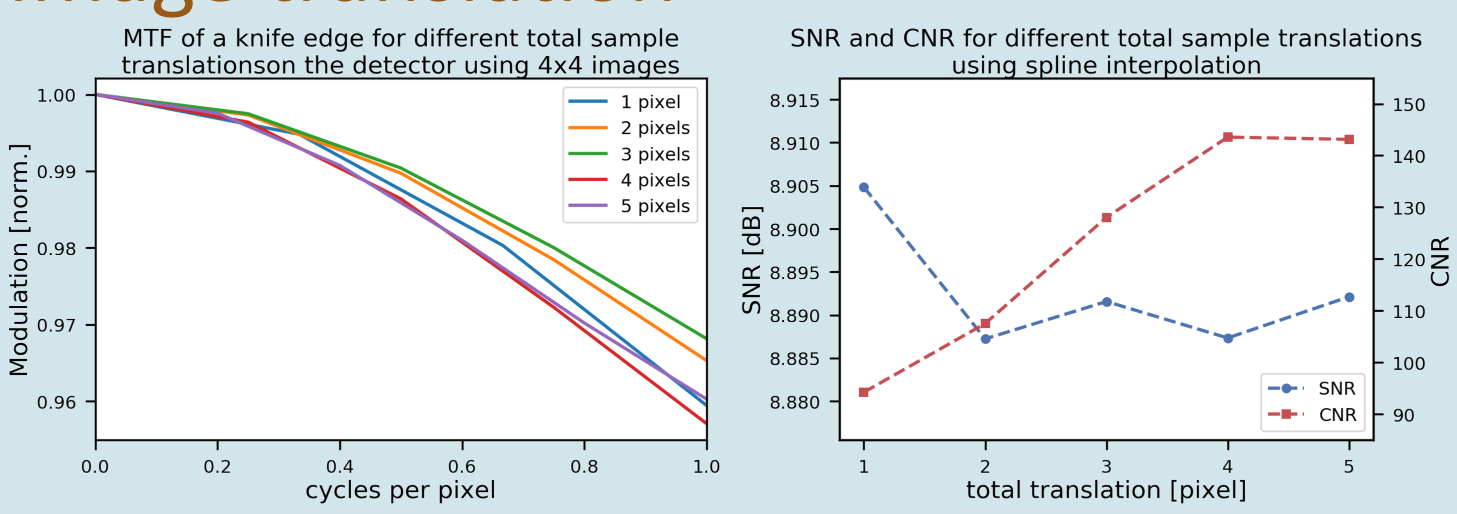

Fig. 4 Different total sample translation on the detector

Examining 4x4 images with 4-times interpolation, best visual results have been achieved with a total image translation of 3 pixels. However, the highest CNR can be achieved with a translation of 4 pixels, i.e. a shift of 1 pixel in (x,y) between the images.

Conclusions

Our experiments have shown that hybrid pixel detectors are a viable choice for super-resolution imaging. The optimal interpolation methods depends on the kind of image. However, the best compromise seems to be *spline*, while *cubic* and *makima* interpolation provide higher CNRs, but perform worse on sharp edges.

Translating the image so that the sample moves 1 pixel per step in (x,y) between images provides the best CNR, while a translation of 0.75 pixels per step is best for sharp features. To gain image details, the sample should be translated using fractions of pixels.

Considering the interpolation factor, the square root of the amount of images is a good guide line to achieve the highest quality. The CNR is almost unaffected by the interpolation factor, while the SNR increases with the amount of images, except when using *nearest neighbour* interpolation.

Method

Our setup consists of a prototype solid anode Excillum micro-focus source and a Pilatus 100K detector. The source has the intrinsic capability to accurately position the e-beam, which makes it possible to precisely move the X-ray spot. To achieve super-resolution, the X-ray spot is moved in a NxN grid pattern and one image is taken per position. Further, the total translation of the sample on the detector is set by calculating the grid spacing based on the geometry of the imaging setup [1].

A high-resolution image is estimated by registering the translation between the low-resolution images [2] and interpolating them onto a finer high-resolution grid [3]. Finally, the resulting high-resolution images are then averaged to create a super-resolution image [4].

Here we investigate the effect on the resulting image using different interpolation methods, upscaling factors, number of low-resolution images, and sample translation on the detector. Further, we demonstrate that this technique can be applied to tomography as well.

Image quality is assessed via the *signal to noise ratio* (SNR), *contrast to noise ratio* (CNR), and the *modulation transfer function* (MTF).

Super-Resolution images

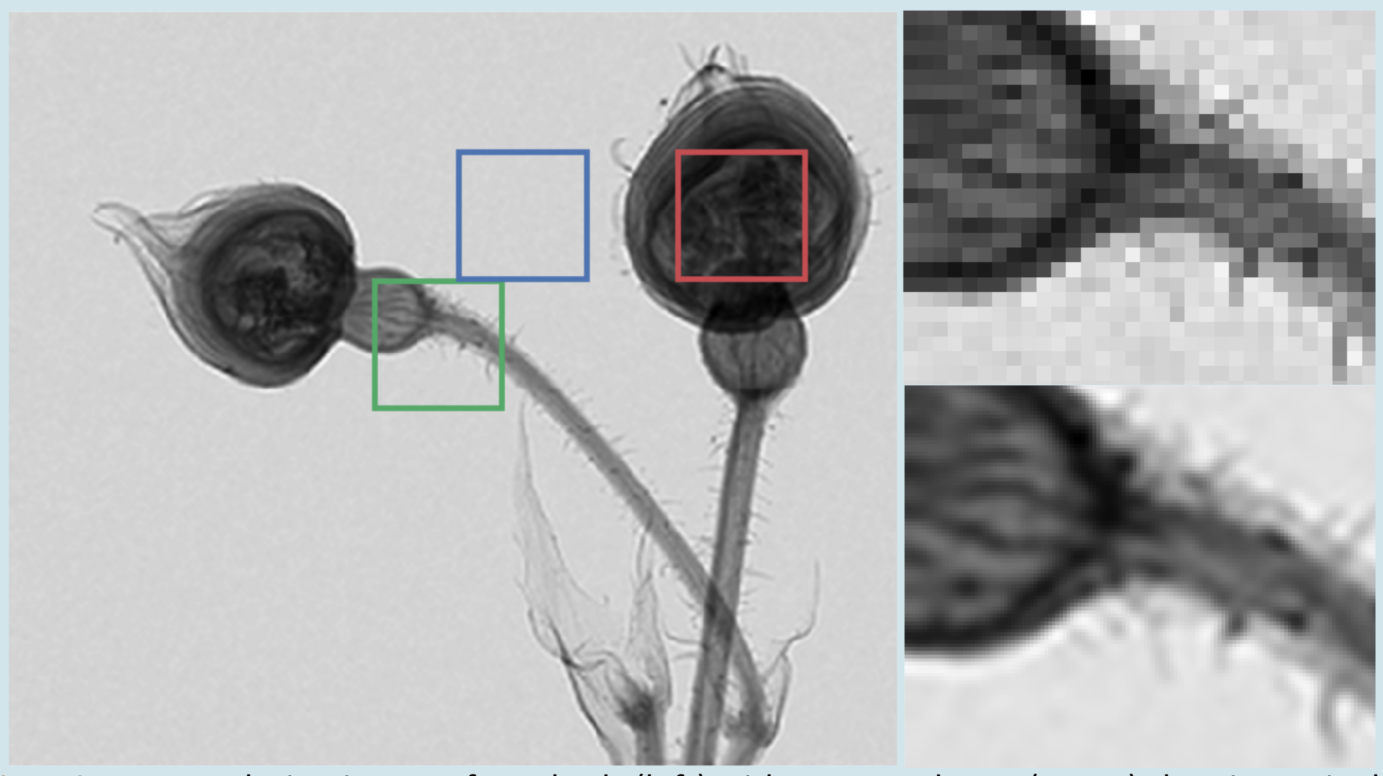

Fig. 5 Super-Resolution image of rosebuds (left) with a zoomed area (green) showing a single image (right top) compared to the super-resolution image (right bottom). The areas used for SNR and CNR calculation are shown in red (signal) and blue (background).

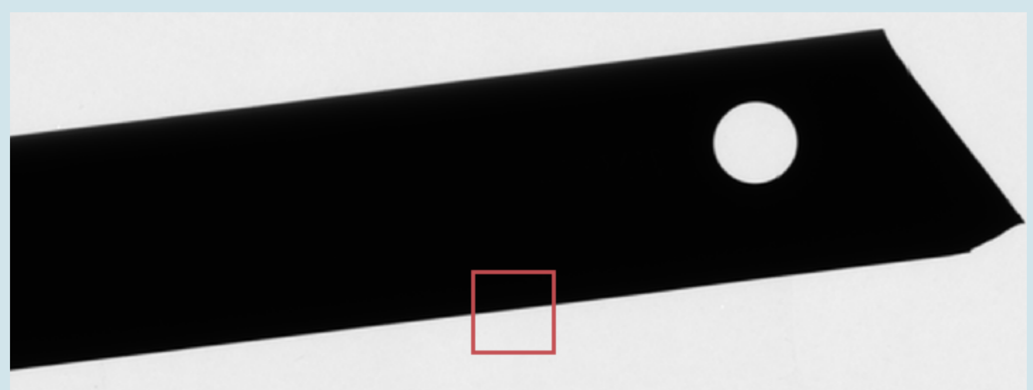

Fig. 6 Knife edge image used for MTF analysis, the used region is marked with a red square. The same region has been used for all shown MTF plots.

Super-Resolution tomography

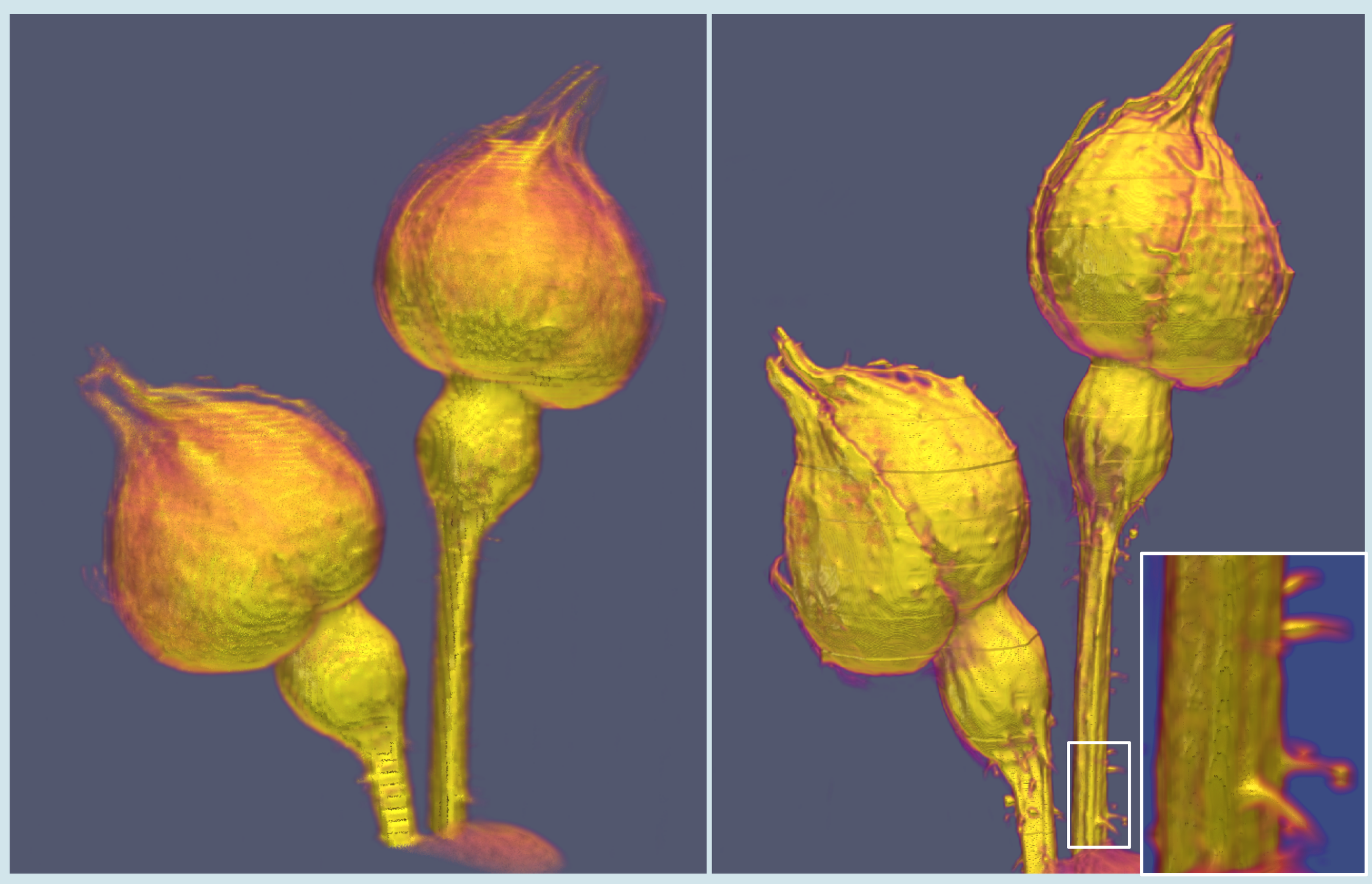

Fig. 7 Regular CT (left), super-resolution CT using 2x2 images per projection (right) showing that more details can be observed, e.g. thorns on the stems (white area)

References

[1] K. Rix, T. Dreier, T. Shen, and M. Bech, *Phys. Med. Biol. (2019, under review)*
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[3] Gilman, A., Bailey, D. G. & Marsland, S. R. in *4th IEEE International Symposium on Electronic Design, Test and Applications (delta 2008)* 55–60 (IEEE, 2008)
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