Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

RESOLUTION IMPROVEMENT OF FREQUENTLY OBSERVED SATELLITE IMAGERY FOR URBAN CHARACTERIZATION

Masayuki KOHIYAMA
Institute of Industrial Science, University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505
Tel: (81)-3-5452-6388 Fax: (81)-3-5452-6389
E-mail: kohiyama@iis.u-tokyo.ac.jp
JAPAN

Fumio YAMAZAKI
School of Advanced Technologies, Asian Institute of Technology
P.O. Box 4, Klong Luang, Pathumthani 12120
Tel: (66)-2-524-6395 Fax: (66)-2-524-5597
Email: yamazaki@ait.ac.th
THAILAND

KEY WORDS: Resolution Improvement, Multi-temporal Imagery, Urban Structure, Remote Sensing

ABSTRACT: This paper proposes the method to develop a high-resolution image of urban properties from frequently observed low-resolution images based on the statistic process assuming urban properties have little temporal change. Because disaster responders sometimes have difficulty to obtain the map data in a digital form especially in developing countries, it is well known that satellite imagery and aerial photographs can support disaster response and rescue activities. But high-resolution images that can provide roads and buildings information expense considerably high when acquiring wide range data by means of aerial photographs or imagery of recently launched satellites with high-resolution sensors. On the other hand, satellite images of spatial resolution of 10 to 100 meter order cost comparatively low. The paper discusses the number of low-resolution images to develop a high-resolution image. First, a one-meter-resolution image derived from an aerial photograph is used as a truth image. Three-meter-resolution image is also evaluated as a reference high-resolution image. Secondly, a nine-meter-resolution image, which simulates an image scanned by a low-resolution sensor of satellites, is evaluated with a randomly selected offset of scan line. The same cell size as a reference image, i.e. three meter is employed for the low-resolution images. Thirdly, a resolution-improved image is synthesized from the average and standard deviation based on each pixel calculation of the simulated images. Then the difference between the reference image and synthesized image is evaluated. Finally, the relationship between the number of low-resolution images and the standard deviation of differences of all pixels in the average image is analyzed. The result quantitatively clarifies that a high-resolution image of urban properties with little temporal change can be developed with a sufficient number of low-resolution images when the precise geolocation is guaranteed.

1. INTRODUCTION

To manage the information of urban properties like roads and structures, remote sensing has the great advantage in rapid acquisition of wide area data, consistent processing of geographic data in a digital form, and so on. In case of disaster emergency response, satellite images are often used in substitution for large-scale maps, especially in the countries where these maps are difficult to obtain (Mouginis-Mark, et al., 2001).

Although aerial photographs and one-meter-order high-resolution satellite images are available to obtain the high-resolution images, cost problem will be confronted. On the other hand, a number of satellite images of ten-to-hundred-order spatial resolution, which were observed in several months, can be provided with a comparatively low cost for the same area. For example, Landsat/ETM+ (panchromatic) and EOS/ASTER can provide images of fifteen-meter resolution with the repeat period of sixteen days. But, with a single image observed by these sensors, road networks are barely distinguished and it is very difficult to discriminate narrow alleys and small isolated houses, which are smaller than the spatial resolution.

Against this limited spatial resolution, about twenty images can be observed in a year with respect to temporal resolution although depending on weather conditions. Therefore, it is meaningful to devise a method to compensate spatial resolution with temporal resolution. Image processing researches, e.g. Kim et al. (1990), Irani and Peleg (1991), Ur and Gross (1992), Schultz and Stevenson (1996), Hardie et al. (1997), and Elad and Feuer (1997), propose

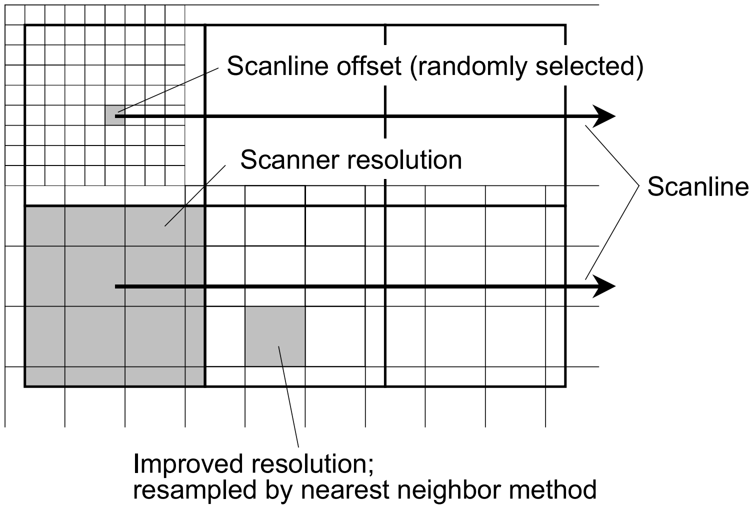

Figure 1 Randomly selected scanline offset and pixel division for resolution improvement

the methods to reconstruct a high resolution image from undersampled images. But there has been no research on the resolution improvement using multi-temporal satellite images from the viewpoint of detection of urban structures. In this paper, a method is proposed to synthesize an image of improved resolution based on statistic process using low cost satellite images of multi-temporal low- or moderate-resolution.

2. RESOLUTION IMPROVEMENT BASED ON MULTI-TEMPORAL SATELLITE IMAGES

Recently, the advanced Global Positioning System (GPS) technology enables us to achieve sub-pixel precision in georeference of satellite imagery. This precision will be improved in the near future and it is promising that you can determine the offset positions of sensor scanlines with higher accuracy than spatial resolution of observed image. Low-spatial-resolution sensors are often on board the satellites with short repeat period, i.e. the temporal resolutions are relatively high. In addition, the development of Stratospheric Platform (SPF) airship system is in progress in Japan, which will be stable platform for observation sensors. Based on this background, it is meaningful to devise and propose techniques to utilize temporal resolution to enhance spatial resolution.

In this study, it is assumed that the positions of the scanline offset are randomly given in multi-temporal observation. A low-resolution image can be regarded as an average of high-resolution image inside of a pixel, and, when the digital numbers of multi-temporal images observed at a certain position are averaged, the operation is equivalent to a cascaded filtering, which corresponds to a low-resolution average filter, for a high-resolution image. Therefore, the average value at a certain position has influences from surrounding pixels, which decrease along with distance. On the other hand, the standard deviation of multi-temporal low-resolution images observed at a certain position becomes large when the difference of digital numbers between neighboring pixels is large, and becomes small when the difference is small. Thus, the standard deviation can be regarded as information to remove the influence from surrounding pixels. From this viewpoint, the following method of resolution improvement is proposed:

1) Select the cell size and grid position of a resolution-improved image.
2) Create an image from a low-resolution image based on the nearest neighbor method using cells selected at the step 1) (hereby, the pixel-divided image) (Figure 1).
3) Create pixel-divided images from multi-temporal low-resolution images.
4) Calculate the average and standard deviation of the multi-temporal pixel-divided images by referring the same cell position.
5) Compare the digital number in the average image D_0 and the average of the eight digital numbers of the surrounding pixels D_{ave}.
6) Calculate the digital number of the resolution-improved image D_1 with D_0 and the digital number in the standard deviation image at the same position D_{SD} by the following conditions:

In case that $D_0 > D_{ave}$, $D_1 = D_0 + \alpha D_{SD}$
In case that $D_0 = D_{ave}$, $D_1 = D_0$
In case that $D_0 < D_{ave}$, $D_1 = D_0 - \alpha D_{SD}$

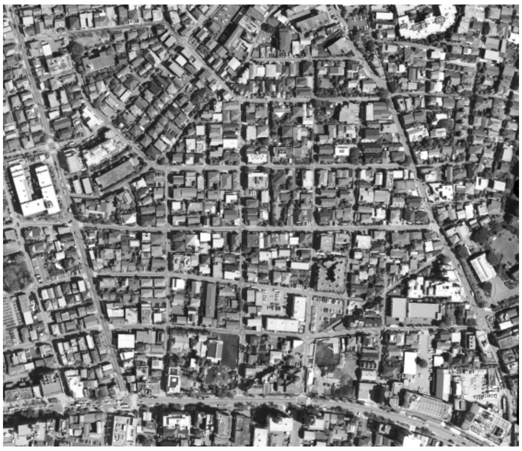

Figure 2: Original aerial photograph
(1m × 1m pixel)

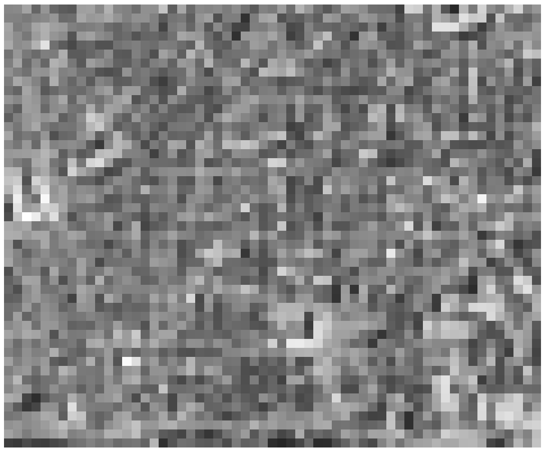

Figure 3: Simulated low-resolution image
(9m × 9m pixel)

Figure 4: Average of twenty images
(3m × 3m pixel)

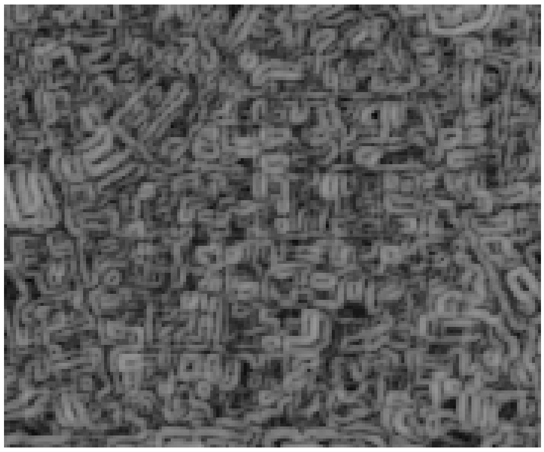

Figure 5: Standard deviation of twenty images
(3m × 3m pixel)
Digital number is three times enlarged.

where α is an amplification coefficient. In this paper, $\alpha = 1$ is assumed for the preliminary study.

3. NUMERICAL EXPERIMENTS

3.1 Required Number of Low-resolution Images for Resolution Improvement

Resolution improvement from 9m × 9m to 3m × 3m is studied, and the number of low-resolution images is analyzed to generate high-resolution image of enough quality. First, an aerial photograph of one-meter resolution (Figure 2) is used to simulate satellite images. The offset positions of scanline are randomly selected based on one-meter unit. A sample of the simulated nine-meter resolution image is shown in Figure 3. Then, three-meter resolution images with the same offset positions are resampled from the nine-meter resolution images based on the nearest neighbor method. The average image (Figure 4) and standard deviation image (Figure 5) are statistically derived from the resampled three-meter resolution images. Finally, the resolution-improved image (Figure 6) is generated based on the steps described in the last section.

The result resolution-improved image is compared with the three-meter resolution image (hereby, the reference image) (Figure 7), which is simulated with the aerial photograph. The differences (errors) between the digital numbers of the resolution-improved image and the reference image are calculated, and the square root of the mean of the squared errors (here by, root mean square, *RMS*), which are considered as error indices, are analyzed for each number of multi-temporal low-resolution images. The relationship between *RMS* and the number of low-resolution images *N* is shown in Figure 8. As a result, there is a tendency that *RMS* decreases when *N* increases. At the point that

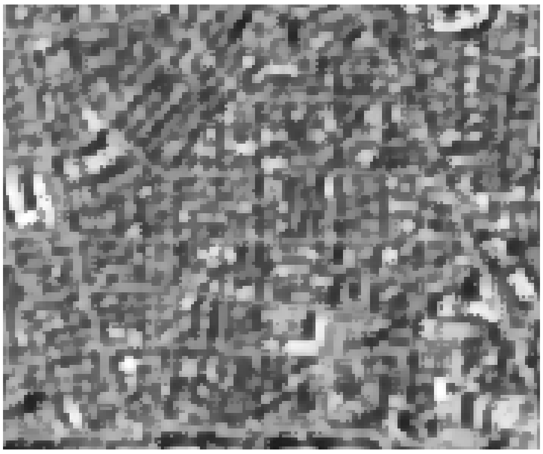

Figure 6 Synthesized resolution-improved image (3m × 3m pixel)

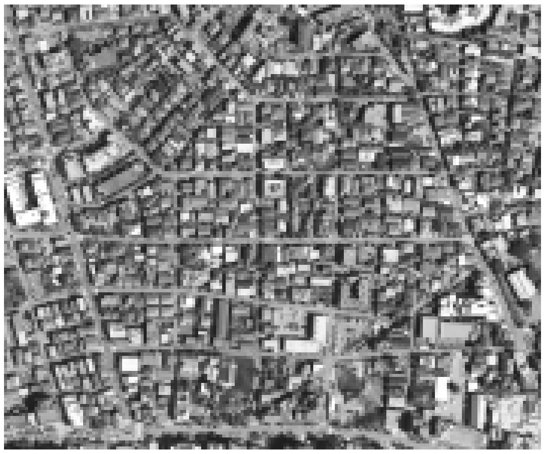

Figure 7 Reference image (3m × 3m pixel)

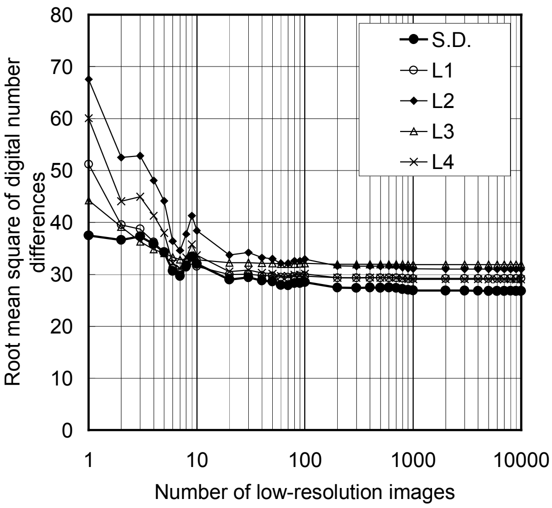

Figure 8 Number of low-resolution images and root mean square of digital number differences between synthesized image and reference image

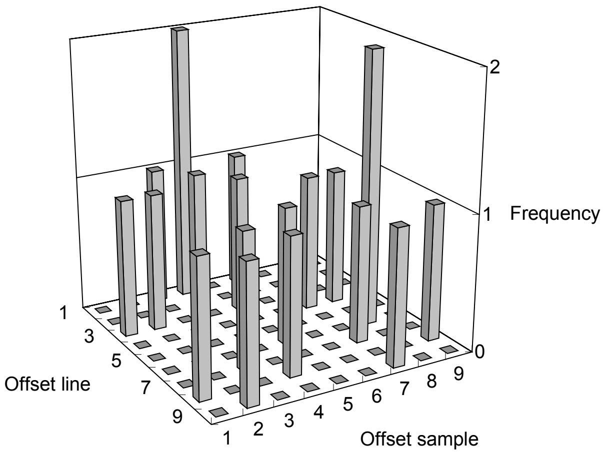

Figure 9 Randomly selected positions of scanline offsets for twenty images

$N = 20$, $RMS = 29.0$ and RMS seems to be stable when N is over 20. The scanline offset positions for $N = 20$ are shown in Figure 9. The synthesized resolution-improved image for $N = 20$ is shown in Figure 6. The roads and isolated buildings, which it is very difficult to distinguish in original low-resolution images, can be recognized with a fairly good ratio from the synthesized image.

3.2 Comparison with Laplacian Filters

The average image can be regarded as a result of a kind of smoothing filtering for high-resolution image. Generally, Laplacian filter and high-pass filter, which exaggerate edge, are used to remove a blur. In this section, the synthesized resolution improved image based on average and standard deviation images is compared with the images deblurred from the average image using the Laplacian filters. The following four filters are used for comparison:

$$L_1 = \begin{pmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{pmatrix},\ L_2 = \begin{pmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{pmatrix},\ L_3 = \begin{pmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{pmatrix},\ L_4 = \begin{pmatrix} -1 & 0 & -1 \\ 0 & 4 & 0 \\ -1 & 0 & -1 \end{pmatrix}$$

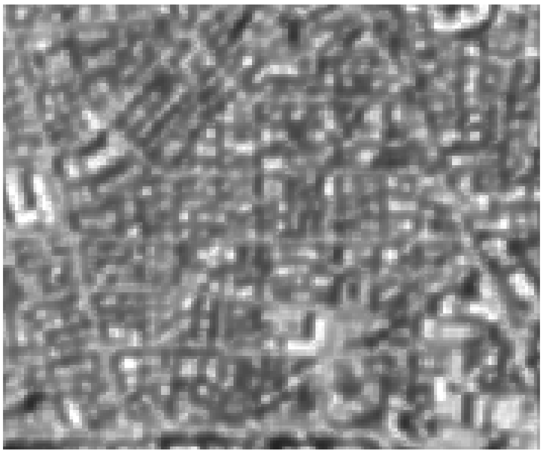

Figure 10 Image deblurred by filter L_1
(3m × 3m pixel)

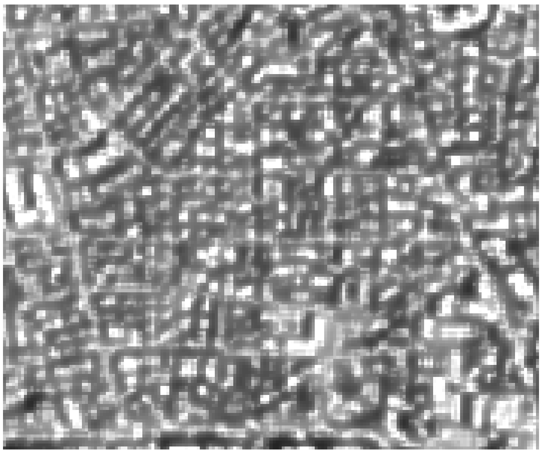

Figure 11 Image deblurred by filter L_2
(3m × 3m pixel)

Figure 12 Image deblurred by filter L_3
(3m × 3m pixel)

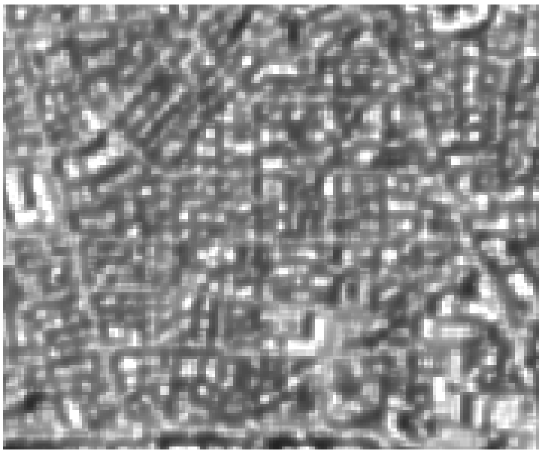

Figure 13 Image deblurred by filter L_4
(3m × 3m pixel)

The images deblurred by the filters L_1, L_2, L_3, and L_4 from the average image ($N = 20$) are shown in Figures 10, 11, 12, and 13, respectively. The *RMS* for each filter is shown in Figure 8. The *RMS* of the proposed method is smaller than that of any result using the filters. In addition to the accurate reproduction of brightness, individual roads and buildings in the synthesized image can be detected more easily than in the images deblurred by the filters.

With regards to the high-pass filter $H = 1/9\ L_2$, the weight coefficient influence is observed for four coefficients, 1, 2, 3, and 4. The *RMS* of each case is shown in Figure 14. Based on the figure, the *RMS* of the proposed method is smaller than that of any coefficient when the number of low-resolution images exceeds 20. In the same way, with regards to the filter L_3, the *RMS* of four coefficients, 1, 2, 3, and 4 are shown in Figure 15. Likewise the high-pass filter, the *RMS* of the proposed method is smaller than that of any coefficient when the number of low-resolution images exceeds 20. These results support that the proposed method improves resolution better than simple deblurring of an average image.

4. CONCLUSIONS

The resolution improvement method based on the average and standard deviation image of multi-temporal low-resolution images is proposed. The results of the numerical experiments to enhance resolution from 9m × 9m to 3m × 3m, it is verified that this method can generate an image, in which the roads and isolated buildings can be distinguished, when the number of low-resolution images is larger than 20. The proposed method can generate better resolution-improved images than simple methods using Laplacian filters to deblur an average image of low-resolution images.

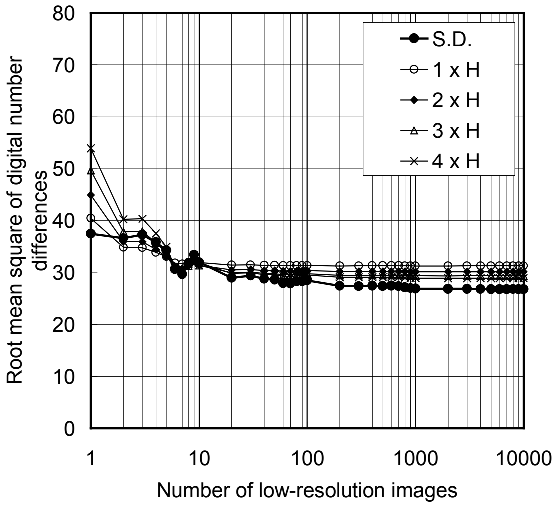

Figure 14 Number of low-resolution images and root mean square of digital number differences between synthesized image and reference image (parametric study on coefficients of filter *H*)

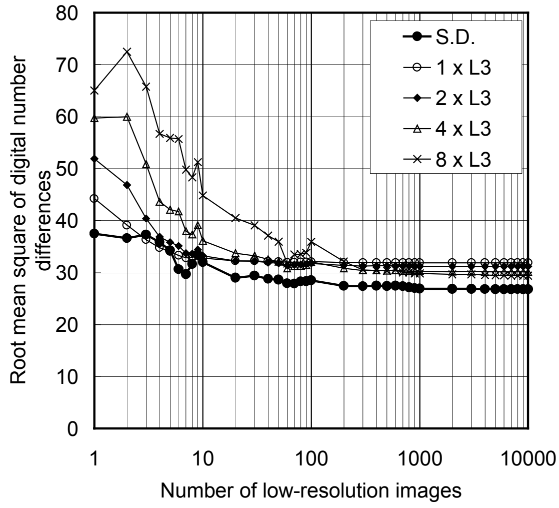

Figure 15 Number of low-resolution images and root mean square of digital number differences between synthesized image and reference image (3) (parametric study on coefficients of filter L_3)

Therefore, images with sufficient observation frequency can generate the resolution-improved image relating to the urban properties, which have relatively little temporal changes, when the precise geolocation is guaranteed, at least in case that the original resolution is higher than 9m.

In a future study, the precise formulation of the proposed method is required considering the resolution enhancement ratio. In addition, the amplification coefficient for standard deviation used in generating resolution-improved images should be analyzed. With respect to evaluation of errors, a new index should be considered from the viewpoint of distinguishability of features like roads, buildings, etc.

REFERENCES

Elad, M. and Feuer, A., 1997. Restoration of a single superresolution image from several blurred, noisy and undersampled measured images, IEEE trans. Image Processing, Vol. 6., No. 12, pp. 1646-1658.

Hardie, R. C., Barnard, K. J., and Armstrong, E. E., 1997. Joint MAP registration and high-resolution image estimation using a sequence of undersampled images, IEEE trans. Image Processing, Vol. 6., No. 12, pp. 1621-1633.

Irani M. and Peleg, S., 1991. Improving resolution by image registration, CVGIP: Graphical Models and Image Processing, Vol. 53, No. 3, pp. 231-239.

Kim, S. P., Bose, N. K., and Valenzuela, H. M., 1990. Recursive reconstruction of high resolution image from noisy undersampled multiframes, IEEE Trans. Acoustics, Speech, Signal Processing, Vol. 38, No.6, pp. 1013-1027.

Mouginis-Mark, P. J., 2001. Cloud-free satellite mosaics for disaster management. Proc. of IGARSS 2001 International Geoscience and Remote Sensing Symposium, CD-ROM.

Schultz, R. R. and Stevenson R. L., 1996. Extraction of high-resolution frames from video sequences, IEEE trans. Image Processing, Vol. 5., No. 6, pp. 996-1011.

Ur, H. and Gross, D., 1992. Improved resolution from subpixel shifted pictures, CVGIP: Graphical Models and Image Processing, Vol. 54, No. 2, pp. 181-186.