SUPER RESOLVED REMOTE SENSING BY FUSION OF MULTI SPECTRAL AND SPATIAL DATA

E. Gur[a], Z. Zalevsky[b,*] and B. Javidi[c]

[a] Faculty of Engineering, Shenkar College of Eng. & Design, Ramat Gan, 52526, Israel – gur.eran@gmail.com

[b] School of Engineering, Bar Ilan University, Ramat Gan, 52900, Israel - zalevsz@eng.biu.ac.il

[c] University of Connecticut Electrical & Computer Engineering Dept., USA - bahram@engr.uconn.edu

KEY WORDS: Engineering, Processing, Retrieval, Algorithms, Image, Resolution, High resolution, Optical

ABSTRACT:

In this paper the authors present a super resolution approach which is based on iterative data fusion algorithms. The proposed data fusion can be implemented using a plurality of spectral images as well as a plurality of images with varied resolution generated from different regions of the field of view. The data fusion suggested in this paper is gradual, allowing the build up of one single high resolution image from low resolution images and partial high resolution images. The iterative procedure used in this paper is based on iterative ping-pong computation between the spatial domain and its spectral distribution, similar to the Gerchberg-Saxton approach but with dynamic parameters. The iterative approach enables the retrieval of high resolution data from mostly-low resolution data. In both approaches mentioned, one may mix high and low resolution information by the insertion of properly defined constrains, and achieve an enhanced image in terms of clarity, resolution, correlation with true data and contrast.

[*] Corresponding author.

INTRODUCTION

A well-known phase retrieval algorithm commonly used for optical beam shaping is the Gerchberg and Saxton (Gerchberg and Saxton, 1972) approach in which knowing the magnitude distribution of an image in the spatial and the spectral domain enables the recovery of the phase distributions. Later work by Misell (Misell, 1973a; Misell, 1973b; Misell, 1973c) extended the algorithm for two arbitrary input and output planes along the optical path. These methods are proven to converge to a phase filter with a minimal mean square error (Fienup, 1978; Fienup, 1982).

The concept presented in the Gerchberg-Saxton paper is simple. One starts with an arbitrary phase-only filter in the object domain multiplying the input object (the original image), after a Fourier transform one obtains a Fourier domain image and imposes the required Fourier magnitude, while maintaining the Fourier phase. An inverse Fourier transform brings us back to the object domain. Since we demand a phase-only signal, we impose the intensity of the input object in this plane. Next, one calculates the Fourier transform and returns to the Fourier domain to iterate the process until an acceptable convergence is obtained.

Gerchberg (Gerchberg, 1974) and Papoulis (Papoulis, 1975) suggested the use of this method for super resolution. However, both presented relatively simple test cases and assumed the properties of all iterations to be identical (except when noise reduction was addressed). An improved Gerchberg-Papoulis algorithm was recently suggested by Gur and Zalevsky (Gur and Zalevsky, 2007a; Gur and Zalevsky, 2007b); however, it supplies good result only if the blurred image is actually a lower resolution version of the required image. Similar approaches providing image resolution enhancement by proper digital image processing interpolation and learning-based algorithms can for instance be seen in Refs. (Gevrekci and Gunturk, 2000; Nguyen and Milanfar, 2000; Joshi *et al*, 2005).

In this paper, the authors propose a modification of the algorithm presented in Ref. (Gur and Zalevsky, 2007a; Gur and Zalevsky, 2007b). In the new algorithm, instead of multiplexing two images, one at high resolution and the other at low resolution, the authors propose a general approach capable of multiplexing a plurality of low and high resolution images. In the proposed approach, the multiplexed images do not have to relate to different regions of the field of view but rather to images that are captured at different spectral wavelengths. In this paper, the authors validate the generalized approach by experiments including both images captured at different spatial resolutions from airborne camera as well as images captured in a multi spectral sensor.

The 2nd section presents the proposed approach. Experimental results are presented in 3rd section. The paper is concluded in the 4th section.

THE PROPOSED ALGORITHM

In this paper the authors address the following situation: We obtain a plurality of low resolution images which can be from different regions in the field of view with lower resolution, or a set of images captured at different wavelengths by a multi-spectral sensor. In addition to the low resolution input images, we obtain a plurality of high resolution images which can be from other regions of the field of view (that may be at different resolution levels) or they may be spectral images captured at shorter wavelengths and thus have higher resolution. Our aim is to reconstruct the higher spatial frequencies by a dynamic iterative procedure.

The flow chart of the proposed algorithm is described in Figure 1. The starting point of the basic algorithm assumes that we possess a plurality of High Resolution (HR) images and a plurality of Low Resolution (LR) images. Each image relates to a different region of the field of view, or we possess several images coming from sensors of different wavelengths while each image contains the full field of view. An overall image is generated from the plurality of given images. The generalized image is vertically divided into N regions. The reconstructed image of the full field of view is either an image combining all of the N regions of the field of view together, or a multiplexing of several spectral images captured at different wavelengths when a different region of the field of view is taken from different wavelengths. In both cases, the first iteration of the newly generated image combines some HR and some LR image regions. Then, a Fourier transform is performed. The Fourier image obtained contains data from all regions of the new image.

Since the lower frequencies are present in the LR image, we impose the lower frequencies constraints from the Fourier transform of the original LR images. Next an inverse Fourier transform is performed. At this stage we replace the various regions of the field of view that were related to HR images by the known a priori HR regions, and we keep the rest of the regions. We again perform a Fourier transform to impose the constraints on lower frequencies and so on. The basic algorithm converges when the difference between images obtained in consecutive iterations is below a certain predefined threshold.

At the final stage, we take the HR reconstructions from regions that were originally imposed by the LR images. The strength of this algorithm with respect to algorithm based directly on Misell's work or Gerchberg and Papoulis' work lies mainly on its dynamic properties. We do not impose all the a priori knowledge at the beginning, but rather start with some of the known constraints and increase the applied constraints according to the improvement in mean-square error results from one iteration to the next.

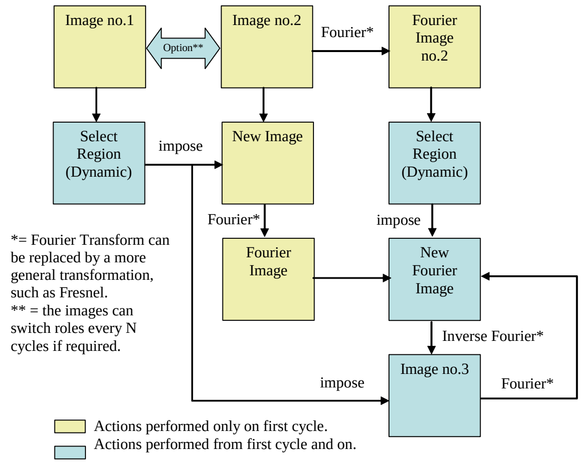
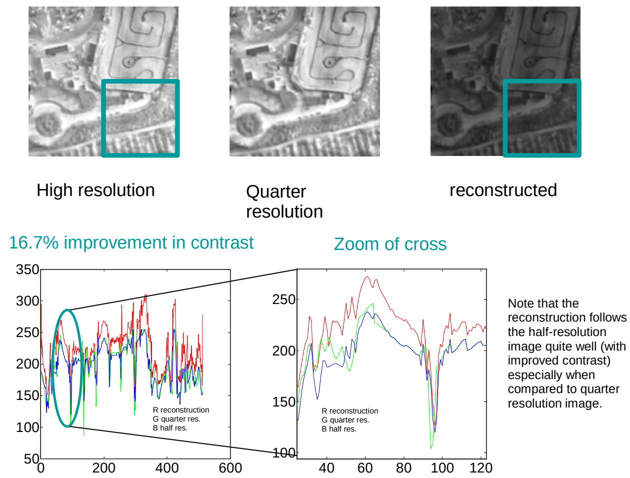


Figure 1. Flow chart of the proposed generalized super resolving approach.

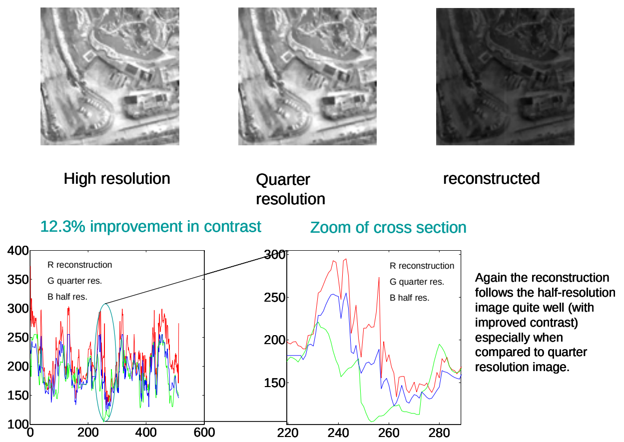
EXPERIMENTAL VERIFICATION

In this section the authors present two types of experimental results, both coming from airborne camera capturing urban area. In Figures 2(a) and 2(b) we present two experimental results. In both, the upper row contains from left to right: a high resolution image, the same image taken at a quarter of the resolution and the obtained reconstruction. The cross section is seen in the lower row. Red corresponds to the reconstruction image, green is the quarter resolution image, and blue is the half resolution image used for comparison. The reconstructed image obtained from the multiplexing of the high resolution image and the quarter resolution image follows the cross section of the half resolution image very well while having an improved contrast by 16.7% in Figure 2(a) and by 12.3% in Figure 2(b). The correlation between the reconstructed image and the HR image is 98.2% and the mean square error is less than 0.8%, for the later test case.

In the second experiment presented in Figure 3, we obtain the photograph of the same scenery using two different wavelengths. We assume that in the shorter wavelength image we succeeded to obtain only the lower right quarter of the image. By the same iterative procedure (but using different parameters) we generate a new image (result) containing high resolution data even outside the imposed data region. In the lower row of Figure 3 one may see the reconstructed result (left) and its cross section (right). An improvement of more than 10% in the contrast is obtained when comparing the reconstruction results (red) and the original image at low resolution (longer wavelength).



(a)



(b)

Figure 2. Experimental results using airborne camera images. (a). Captured image #1. (b). Captured image #2. In both cases, the upper row contains from left to right: a high resolution image, same image at quarter of resolution, and the reconstruction results. The cross section is seen in the lower row. Red is the reconstruction, green is the quarter resolution image, and blue is the half resolution image used for comparison. The reconstructed image obtained from multiplexing of the high resolution image and quarter resolution image follows the cross section of the half resolution image very well while having an improved contrast (improvement by 16.7% in (a), and 12.3% in (b)).

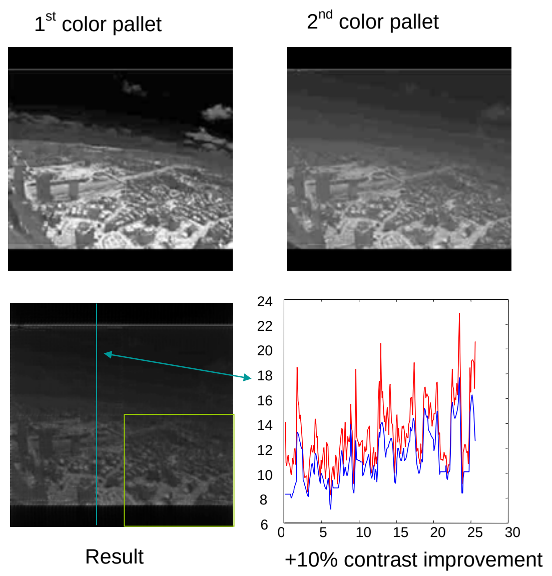


Figure 3. Experimental results taken from airborne multi spectral sensor at mid infra-red of 3.8-4.1 micron (left image of upper row) and at wavelength of and 4.5-4.8 micron (right image of upper row). In the lower row one may see the reconstructed result (left) and the obtained cross section (right). An improvement of more than 10% in the contrast is obtained when comparing the reconstruction (red) and the original image at low resolution (longer wavelength).

CONCLUSIONS

In this paper, the authors have presented a generalized approach for digital super resolution while using a plurality of images with different resolutions corresponding to either different regions of the field of view of the scene or from a multi spectral imager. The proposed algorithm was experimentally tested on images downloaded from an airborne camera capturing an urban scene at different resolutions and different wavelengths. Resolution improvement by a factor of two was observed in the reconstructed image by comparing it with an experimentally captured reference image. In addition, a contrast improvement of more than 10% was observed.

References

Fienup J. R., 1978. Reconstruction of an object form the modulus of its Fourier transform. *Opt. Lett.* 3, pp. 27-29.

Fienup J. R., 1982. Phase retrieval algorithms – a comparison. *Applied Optics* 21, pp. 2758-2769.

Gerchberg R. W. and Saxton W. O., 1972. A practical algorithm for determination of phase from image and diffraction plane picture. *Optik* (Stuttgart) 35, pp. 237-246.

Gerchberg R. W., 1974. Super-resolution through error energy reduction. *Optica Acta* 21, pp. 709-720.

Gevrekci M. and Gunturk B.K., 2007. Superresolution under photometric diversity of images. *EURASIP Journal on Applied Signal Processing* 2007, pp. 205-205.

Gur E. and Zalevsky Z., 2007a. Single image digital super resolution: A revised Gerchberg-Papoulis algorithm. *IAENG Int. Journal of Computer Science* 34, pp. 251-255.

Gur E. and Zalevsky Z., 2007b. Iterative single-image digital super-resolution using partial high-resolution data. *Lecture Notes in Engineering and Computer Science, WCE2007*, pp. 630-634.

Joshi M., Chaudhuri S. and Panuganti R., 2005. A learning-based method for image super-resolution from zoomed observations. *IEEE Transactions on Systems, Man, and Cybernetics*, Part B 35, pp. 527-537.

Misell D. L., 1973a. An examination of an iterative method for the solution of the phase problem in optics and electron optics: I. Test calculations. *J. Phys. D: Appl. Phys.* 6, pp. 2200-2216.

Misell D. L., 1973b. A method for the solution of the phase problem in electron microscopy. *J. Phys. D: Appl. Phys.* 6, L6-L9.

Misell D. L., 1973c. An examination of an iterative method for the solution of the phase problem in optics and electron optics: II. Sources of error. *J. Phys. D: Appl. Phys.* 6, pp. 2217-2225.

Nguyen N. and Milanfar P., 2000. A wavelet-based interpolation-restoration method for super resolution. *Journal of Circuit Systems Signal Process* 19, Springer, pp. 321-338.

Papoulis A., 1975. A new algorithm in spectral analysis and band-limited extrapolation. *IEEE Trans. Circuits Syst.* 22, pp. 735-742.