Signal Processing, Vol. 39, No. 7, July 1991 and in a paper entitled FAST REGULARIZED DECONVOLUTION IN OPTICS AND RADARS, by J. B. Abbiss et al., presented at the 3rd IMA Conference on Mathematics in Signal Processing. These techniques use linear algebra and matrix techniques to restore signals or images from a limited discrete data set.

The previously described techniques have a number of drawbacks with regard to optical sensors. First, only one of these techniques is directed toward a diffraction limited device. In addition, these techniques often produce systems of equations which cannot be solved due to the practical constraints on computing power. Furthermore, none of the previously described techniques specify either the types of detectors or other system parameters which are used along with these techniques.

It is, therefore, an object of the present invention to provide a technique for optimally increasing the resolution of an optical sensor that is diffraction limited (using super-resolution techniques) without using a substantially larger aperture.

SUMMARY OF THE INVENTION

The invention provides a method of improving the spatial resolution of an object using a background reconstruction approach wherein a localized object containing high spatial frequencies is assumed to exist inside a background scene containing primarily low and/or very high spatial frequencies compared to the spatial frequencies of the localized object. The imaging system cannot pass these high spatial frequencies (neither the high frequencies of the object, nor the very high frequencies of the background). The background image's low spatial frequencies are used to reconstruct the background scene in which the localized object is situated. Using this reconstructed background and the space limited nature of the localized object (i.e. it is only present in part of the scene, not the entire scene), the high spatial frequencies that did not pass through the optical system are restored, reconstructing a detailed image of the localized object.

The improvement comprises filtering the noisy blurred background data of the same scene to obtain noise suppressed data; applying estimations of point spread functions associated with the noise suppressed data and optical system to estimates of the noise suppressed data to obtain a reconstructed background image ($I_r(X)$); and low pass filtering the noisy blurred scene data containing the object to be reconstructed (D**1**) and using the reconstructed background image ($I_r(x)$) to eliminate the background data from the image data to obtain a reconstructed image of an object with increased spatial resolution.

BRIEF DESCRIPTION OF THE DRAWINGS

The above objects, further features and advantages of the present invention are described in detail below in conjunction with the drawings, of which;

FIG. **1** is a general block diagram of the optical sensor according to the present invention;

FIG. **2** is a diagram of a linear detector array tailored to the present invention;

FIG. **3** is a diagram of a matrix detector array tailored to the present invention;

FIG. **4** is a diagram illustrating the size of an individual detector tailored to the present invention;

FIG. **5** is a diagram illustrating how the detector grid is sized with respect to the central diffraction lobe;

FIG. **6** is a diagram of a multi-linear detector array tailored to the present invention;

FIG. **7** is a diagram of another version of a multi-linear detector array tailored to the present invention;

FIG. **8** is diagram illustrating the operation of a beam splitter as part of an optical system tailored to the present invention;

FIGS. **9**A–B represents an image scene and a flow diagram of the non-linear background reconstruction technique of the image scene according to the present invention;

FIG. **10** is a diagram illustrating the Richardson-Lucy background reconstruction portion of the non-linear image processing technique according to the present invention;

FIG. **11** is a diagram illustrating the Object Reconstruction and background subtraction portion of the non-linear image processing according to the present invention;

FIG. **12** is a schematic illustrating the Fourier Transform characteristic of binotf.

FIG. **13** is a schematic of the relationship of binmap to the object of interest within a window of a particular scene according to the present invention; and

FIGS. **14**A–D show the effects of super-resolution of simulated bar targets using the non-linear reconstruction technique according to the present invention;

FIGS. **15**A–D show the Fourier analysis of simulated bar targets associated with FIGS. **14**A–D;

FIGS. **16**A–C show simulated images associated with a thinned aperture optical system configuration using non-linear method.

FIGS. **17**A–C show the super-resolution of an image of a figure taken from a CCD camera and reconstructed using the non-linear method according to the invention;

FIGS. **17**D–F show the Fourier image analysis of the image of FIGS. **17**A–C;

FIGS. **18**A–B show the Fourier analysis of superimposed truth, blurred, and reconstructed images as function of frequency for SNR values of 50 and 100, respectively;

FIG. **19** is a flow diagram of the linear algebra background reconstruction technique according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a method of super-resolution of an image for achieving resolutions beyond the diffraction limit. This is accomplished by a method of background reconstruction, wherein a localized object containing high spatial frequencies is assumed to exist inside a background scene containing primarily low and/or very high spatial frequencies compared to the spatial frequencies of the localized object. The point spread function (PSF) of an optical system causes the background data to blend with and flow over objects of interest, thereby contaminating the boundaries of these objects and making it exceedingly difficult to distinguish these objects from the background data. However, if one knows or can derive the background, then the object may be disentangled from the background such that there will exist uncontaminated boundaries between the object and the background scene. Another way of describing the effect of a PSF is to note that the spatial frequencies associated with the object of interest which lie beyond the optical system cutoff frequency are lost. In the background reconstruction approach, a localized object such as a tractor having high spatial frequencies is super-resolved