

A key quantity used to construct the RPI matrix is the regularization parameter which controls the image restoration. Larger parameter values protect the restored image from the corrupting effects of the optical system but result in a restored image which has lower resolution. An optimum or near optimum value for the regularization parameter may be derived automatically from the image data. Singular value decomposition (SVD) of the imaging operator matrix may be used to compute the RPI matrix. By estimating the noise or error level of the degraded image the singular values of the matrix determine the extent to which the full information in the original scene may be recovered. Note that the use of the SVD process is not essential in determining the RPI matrix, and other methods such as QR decomposition of the imaging matrix may also be used to achieve essentially the same result.

The imaging matrix size increases approximately as the square of the image size, and the computational burden associated with forming the RPI of the imaging matrix quickly becomes intolerable. However, in the special case that the image and object fields are the same size and are sampled at the same intervals (as is the case here), the imaging matrix can be expanded into circulant form by inserting appropriately positioned, additional columns. A fundamental theorem of matrix algebra is that the Fourier transform diagonalizes a circulant matrix. This allows the reduction of the image reconstruction algorithm to a pair of one dimensional fast Fourier transforms, followed by a vector—vector multiplication, and finally an inverse one dimensional fast Fourier transform. This procedure allows the image restoration by this Tikhonov regularization technique to be done entirely in the Fourier transform domain, dramatically reducing the time required to compute the reconstructed image. FIG. 19 provides an illustration of the steps taken to obtain the reconstructed image using the linear transform method.

A flow diagram of the Linear Algebra Technique according to the present invention is shown in FIG. 19. Referring now to FIG. 19, the technique first converts the imaging data collected by the optical system of the sensor into a matrix of the form $g_1(i,j) = \sum_m \sum_n h(i-m, j-n) f(m,n) + n_1(i,j)$, where h is a matrix representation of the point spread function of the optical system and f is the matrix representation of the unblurred background with the embedded object, while n_1 is the matrix representation of the additive white noise associated with the imaging system (module 12). Next, imaging data g_2 comprising the image scene data which contains only the background data is obtained in the form of $g_2(i,j) = \sum_m \sum_n h(i-m, j-n) b(m,n) + n_2(i,j)$ where b is a matrix representation of the unblurred background data taken alone and n_2 is a matrix representation of additive system white noise (module 14). Both g_1 and g_2 are then low-pass filtered to the cut-off frequency of the optical system to reduce the effects of noise (module 15). Module 16 then shows the subtraction step whereby the matrix representation (g_3) of the difference between blurred scene data containing the background and object of interest (g_1) and the blurred scene containing only the background data (g_2) is formed as ($g_1 - g_2$). Next, the position and size of the object of interest is specified by choosing x,y coordinates associated with image matrix ($g_1 - g_2$) (module 18). A segment of sufficient size to contain the blurred object in its entirety is then extracted from the matrix representation of ($g_1 - g_2$), as shown in Module 20. That is, an area equal to the true extent of the local object plus its diffracted energy is determined. An identically located segment (i.e. segment having the same x,y coordinates) is extracted from the blurred background scene

matrix g_2 as shown in module 22. The two image segments output from module 15 and 20 are then input to module 24 to restore g_2 and ($g_1 - g_2$) using n th order Tikhonov regularization. The restored segments are then added together as shown in step 26; and the area containing the restored object of interest is extracted therefrom, as shown in module 28.

The resulting reconstructed image includes much of the spatial resolution which was lost due to diffraction blurring effects.

It should be noted that the present invention is not limited to any one type of optical sensor device. The principles which have been described herein apply to many types of applications which include, but are not limited to, Optical Earth Resource Observation Systems (both Air and Spaceborne), Optical Weather Sensors (both Air and Spaceborne), Terrain Mapping Sensors (both Air and Spaceborne), Surveillance Sensors (both Air and Spaceborne), Optical Phenomenology Systems (both Air and Spaceborne), Imaging Systems that utilize optical fibers such as Medical Probes, Commercial Optical Systems such as Television Cameras, Telescopes utilized for astronomy and Optical Systems utilized for Police and Rescue Work.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and details may be made therein without departing from the spirit and scope of the present invention.

What is claimed is:

1. In an optical system having a detector means and processor means in which image data is obtained comprising noisy blurred scene data containing an object to be reconstructed (D1), and noisy blurred background data (D2) of the same scene, an improved method for increasing the spatial resolution of the imaging data produced by the diffraction limited optical system, the improvement therewith comprising:

filtering the noisy blurred background data (D2) of the same scene to obtain noise suppressed data;

applying estimations of point spread functions associated with the noise suppressed data and optical system and 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 (D1) and using the reconstructed background image ($I_r(x)$) to eliminate the background data from said image data to obtain a reconstructed image of the object with increased spatial resolution.

2. In an optical system having a detector means and processor means in which image data is obtained comprising noisy blurred scene data containing an object to be reconstructed (D1), and noisy blurred background data (D2) of the same scene, an improved method for increasing the spatial resolution of the imaging data produced by the diffraction limited optical system, the improvement therewith comprising:

filtering the noisy blurred background data (D2) of the same scene to obtain noise suppressed data;

applying estimations of point spread functions associated with the noise suppressed data and optical system in 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 (D1) and using the reconstructed background image ($I_r(x)$) to eliminate the background data from said image data to obtain a reconstructed image of the object with increased spatial resolution;