METHOD OF DIGITAL IMAGE ENHANCEMENT AND SHARPENING

PRIORITY CLAIM

This application claims the benefit of the filing date of U.S. Provisional Patent Application Ser. No. 60/100,136, filed Sep. 14, 1998 for "METHOD OF DIGITAL IMAGE ENHANCEMENT AND SHARPENING BASED ON MINIMUM GRADIENT SUPPORT CONSTRAINT."

TECHNICAL FIELD

The present invention relates in general to image processing, and, in particular, to image enhancement and sharpening.

The method, for example, can be applied to optical image processing, for image restoration and sharpening in biomedical, geophysical, astronomical, high definition television, re-mote sensing, and other industrial applications.

BACKGROUND ART

Comprehensive coverage of the prior art may be found, for example, in W. K. Pratt, "Digital Image Processing," 2nd Edition, John Wiley and Sons, NY (1988); H. Stark, "Image Recovery; Theory and Application," Academic Press, Inc., Harcout Brace Jovanovich Publishers, New York (1987); R. C. Gonzalez and P. Wintz, "Digital Image Processing," 2nd Edition, Addison-Wesley Publishing Company, Inc., Advanced Book Program, Reading, Mass. (1987); and R. L. Lagendijk and J. Biemond, "Iterative Identification and Restoration of Images," Kluwer International Series in Engineering and Computer Science, Kluwer Academic Publishers, Boston, Mass., (1991).

There have been several attempts to develop a method of image processing and restoration based on the solution of the linear ill-posed inverse problem:

$$d=Bm, \tag{1}$$

where d is the blurred (or degraded) image, m is original (or ideal) image, and B is the blurring linear operator of the imaging system. Note that the original image, as well as the blurred image, can be defined in a plane (2-D image: m=m(x,y), d=d(x,y)) or in a volume (3-D image: m=m(x,y, z), d=d(x,y,z)).

A wide variety of electron-optical devices obey equation (1) with different blurring operators as noted by C. B. Johnson et al., in "High-Resolution Microchannel Plate Image Tube Development," Electron Image Tubes and Image Intensifiers II, Proceedings of the Society of Photo-Optical Instrumentation Engineers, Vol. 1449. I. P. Csorba, Ed. (1991), pp. 2–12. These devices are used in various biomedical imaging apparatus, including image intensifier-video camera (II-TV) fluoroscopic systems (see S. Rudin et al., "Improving Fluoroscopic Image Quality with Continuously Variable Zoom Magnification," Medical Physics. Vol. 19 (1991), pp. 972–977); radiographic film digitizers (see F. F. Yin et al., "Measurement of the Presampling Transfer Function of Film Digitizers Using a Curve Fitting Technique," Medical Physics, Vol. 17 (1990), pp. 962–966); radiographic selenium imaging plates (see P. J. Papin and H. K. Huang, "A Prototype Amorphous Selenium Imaging Plate System for Digital Radiography," Medical Physics, Vol. 14 (1987), pp. 322–329); computed radiography systems (see S. Sanada et al., "Comparison of Imaging Properties of a Computed Radiography System and Screen-Film Systems." Medical Physics, Vol. 18 (1991), pp. 414–420; H. Fujita et al., "A Simple Method for Determining the Modulation Transfer Function in Digital Radiography," IEEE Transactions on Medical Imaging, Vol. 11 (1992), pp. 34–39); digital medical tomography systems (see M. Takahashi et al., "Digital 'IV Tomography: Description and Physical Assessment," Medical Physics, Vol. 17 (1990), pp. 681–685).

Geophysical, airborne, remote sensing, and astronomical blurred images also can be described by equation (1) (see M. Bath, "Modern Spectral Analysis with Geophysical Applications," Society of Exploration Geophysicists, (1995), 530 pp.; C. A. Legg, "Remote sensing and geographic information systems," John Wiley & Sons, Chichester, (1994), 157 pp.).

Most prior efforts to solve the problem: (1) are based on the methods of linear inverse problem solutions. Inverse problem (1) is usually ill-posed, i.e., the solution can be non-unique and unstable. The conventional way of solving ill-posed inverse problems, according to regularization theory (A. N., Tikhonov, and V. Y., Arsenin, "Solution of ill-posed problems," V. H. Winston and Sons., (1977); M. S., Zhdanov, "Tutorial: regularization in inversion theory," Colorado School of Mines (1993)), is based on minimization of the Tikhonov parametric functional:

$$P^{\alpha}(m)=\phi(m)+\alpha s(m), \tag{2}$$

where $\phi(m)$ is a misfit functional determined as a norm of the difference between observed and predicted (theoretical) degraded images:

$$\phi(m)=\|Bm-d\|^2=(Bm-d,\ Bm-d). \tag{3}$$

Functional s(m) is a stabilizing functional (a stabilizer).

It is known in the prior art that there are several common choices for stabilizers. One is based on the least squares criterion, or, in other words, on L_2 norm for functions describing the image:

$$S_{L_2}(m)=\|m\|_2=(m,m)=\int_V m^2 dv=min, \tag{4}$$

where V is the domain (in 2-D space or in 3-D space) of image definition, and (. . . , . . .) denotes the inner product operation.

The conventional argument in support of this norm comes from statistics and is based on an assumption that the least square image is the best over the entire ensemble of all possible images.

Another stabilizer uses minimum norm of difference between the selected image and some a priori image m_{apr}:

$$S_{L_2 apr}(m)=\|m-m_{apr}\|^2=\text{min}. \tag{5}$$

This criterion, as applied to the gradient of image parameters ∇m, brings us to a maximum smoothness stabilizing functional:

$$s_{max\ sm}(m)=\|\nabla m\|^2=(\nabla m,\ \nabla m)=\text{min}. \tag{6}$$

Such a functional is usually used in inversion schemes. This stabilizer produces smooth images. However, in many practical situations the resulting images don't describe properly the original (ideal) image. Inversion schemes incorporating the aformentioned functional also can result in spurious oscillations when m is discontinuous.

It should be noted that in the context of this disclosure, "image parameters" is intended to describe the physical properties of an examined media. Such parameters include