COMPUTER IMAGE MANIPULATION FOR RESTORATION AND ENHANCEMENT

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Summary This paper briefly outlines a few ideas involved in the use of the versatility of high speed digital computers for natural photographic quality image restoration and enhancement. The subject of image digitization is briefly mentioned followed by three models for image restoration. The linear shift invariant (isoplanatic) model relies on a rich body of knowledge in the form of two dimensional linear systems theory. While the linear isoplanatic model is useful for a variety of degradating phenomena, the linear anisoplanatic and nonlinear models often provide further insight into specialized phenomena. Image restoration may often be followed by enhancement techniques which focus on image manipulations for presentation purposes. The psychophysics of vision play a major role in the development of this aspect as do heuristic techniques which tend to focus on known but often unexplainable human viewing responses. Examples from certain nonlinear enhancement processes are presented.

Introduction The advent of high speed general purpose digital computers has reached the stage where it is becoming feasible to perform mathematical or algorithmic processes on images of natural photographic quality. From an analysis viewpoint an image is nothing more than a two dimensional function whose variation in grey scale describe pictorial information. Because man has been somewhat successful in analyzing one dimensional signals with computational techniques, it is not unreasonable to expect that, due to the disproportionately large role that the eye plays in human experiences, there will undoubtedly be an increasing use of computers for manipulation of such natural images. However in the context of a communication system, the human viewing mechanism has yet to lend itself to a viable model for analysis purposes. Thus a proper fidelity criterion for optimum telemetry and communication systems is not readily available. In fact if we attempt to borrow from one dimensional processes, we immediately see that the prevalent mean square error fidelity criterion is definitely a poor choice for the viewing process. While the optimum distortion measure has yet to be found for the two dimensional imaging process, the power of both linear and nonlinear

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mathematical operations afforded by the computer has provided for image manipulation independent of that knowledge.

Traditionally the computer has been used to “restore” an image to its original quality according to some mathematical manipulation which is intended to invert some physical degradation phenomenon experienced in the formation of the image in the first place. Thus the concept of image restoration is one of attempting to recover losses suffered in the optical imaging system due to a variety of degradations which can be modeled from the very simple to the extremely complex. On the other hand, the computer can be used to “improve” the quality of an image without recourse to knowledge of degrading phenomena resulting in the concept of image enhancement. Both mathematical and heuristic techniques are utilized in this process with major emphasis upon the “viewing” of the image for extraction of information which may have not been so readily apparent in the pre-enhanced original.

**A Priori Correction**  It, of course, goes without stating, that any a priori image quality improvement should be attempted to minimize computational restoration and enhancement complexity a posteriori (after the image has been formed). Such a priori techniques range from using optimum focus, exposure, camera adjustments, chemical developments etc. to the more sophisticated ideas of shutter modulation techniques [1] and binary mask aperture [2] for imaging with the minimization of atmospheric and other degradations. However often a priori conditions are not controllable and/or degradations still exist. It then becomes necessary to enlist the power of the computer for restoration processes.

**Digitization Process**  One of the immediate requirements for computer image processing is a high resolution input output mechanism for scanning and displaying quality images. Various systems exist for such I/O operations and it is not the objective here to survey the available devices. However, if the image is modeled as a two dimensional function \( i(x, y) \geq 0 \) where \( x, y \) are integers ranging from 1 to \( N \) then a square matrix of \( N^2 \) numbers can be used to represent the image. The resolution of the image in the computer should be on the order of 256 x 256 or larger and a power of 2 for computational convenience. Typically the digitization process can be envisioned as a two dimensional sampling procedure where uniformity of samples and quantization noise play a major role. Concisely stated, the digitization and display processes are far from linear and introduce degradation (hopefully known) which must be compensated for.

**Image Restoration-Linear Shift Invariant Phenomena**  Probably the simplest mathematical model for the image process is given by a two-dimensional linear system
where the image, \(i(x, y)\), is the output of a linear system whose input was an object \(o(x, y)\). The object suffers degradation introduced by a system response \(h(.)\) such that

\[
i(x_i, y_i) = \int \int o(x_0, y_0) h(x_i - x_0, y_i - y_0) \, dx_0 \, dy_0
\]  

(1)

\(h(x_i, y_i, x_0, y_0)\) is also known as the point spread function and for isoplanatic systems becomes

\[
h(x_i, y_i, x_0, y_0) = h(x_i - x_0, y_i - y_0)
\]  

(2)

Thus the image is the two dimensional convolution of the object and a point spread function. Ideally it is desirable that the point spread function be a dirac delta function in which case the image equals the object. In fact, such is not the case and the power of linear systems theory can be brought to bear on the problem of restoring the image to as close a representation of the object as is possible. Thus for isoplanatic degrading phenomena such as defocus, certain linear motion, simple spherical aberrations, certain atmospheric degradation, and additive noise the mathematical tools are available for computer correction of such processes. Inverse and linear least square filters are typically employed for image restoration with gradients, Laplacians, and higher order spatial derivatives often being useful approximants. Finally, it is possible, within the linear theory to investigate resolving beyond the diffraction limit utilizing the tools of analytic continuation and extrapolation.

**Image Restoration-Linear Shift Varying Phenomena** For more complicated processes, the anisoplanatic model may be more relevant in which case the point spread functions \(h(x_i, y_i, x_0, y_0)\), is different at each point in the two dimensional plane. Consequently our convolution equation is invalid and we must revert to equation (1) for our model and integral equation definition. Phenomena describable under these assumptions include geometric distortion correction, nonuniform and turbulent atmosphere, nonlinear motion degradation, coma, tilt in cylindrical lenses and others too numerous to enumerate. Often it is possible to find nonlinear transformations that map the image into a space in which linear systems theory can then be utilized to correct for the degradation allowing an inverse nonlinear transformation to describe the restored image [3]. High speed computational techniques become quite significant for these processes.

**Image Restoration-Nonlinear Model** Possibly a more relevant model for certain imaging situations is that of a multiplicative process in which the image is assumed to be comprised of the product of an illumination function and a reflected function [4]. The power of homomorphic filtering can then be enlisted to separate the processes and filter multiplicative noise in the traditional linear systems technique. The procedure is similar to that suggested for linearizing certain coma and motion phenomena but is historically older.
**Image Enhancement-Psychophysics of Vision** While the computer can be used quite successfully to “restore” images due to some correctly modelled degradating phenomenon, its power does not stop here. Specifically, it is possible to model the human viewing process such that an optimum display is computed for the human as a communication sink. While work is still quite limited in this area, certain combinations of logarithmic, linear, and exponential processes seem to provide more pleasing viewing than would normally be expected. Indeed if a viable fidelity criterion could be developed for the human eye, then all the powers of information and communication theory could be directed toward optimal use of that channel between the computer image and man.

**Image Enhancement-Heuristics** Heuristic techniques, for lack of a better description, have been developed for improving the quality of images with some success. Unsharp masking [5], contrast enhancement, and crispening have all been utilized in computer image processing. Most such techniques are linear and shift invariant and therefore fit well into the linear filter theory but are not necessarily designed to correct for a specific degradation. Simply stated, the eye appears to respond well to high spatial frequencies which is what these techniques tend to emphasize. In addition some nonlinear averaging combined with thresholding [6] can be utilized in an anisoplanatic filter for local region correction and variation. One particularly exciting technique which aids the human in viewing computer processed images is the use of pseudo color. It is possible to use the large dynamic range of human response to color as a tool in increasing the effective dynamic range of monochrome images where a human has a typically limited dynamic response. Thus pseudo color is the use of color in displaying black and white images. Typically gray scales close together are displayed in colors far apart thus emphasizing subtle gradations in image intensity. Other techniques include the use of spatial filtering and pseudo color to emphasize high spatial frequency information in one color and intermediate and low spatial frequencies in other colors. Needless to say, the results are striking.

Two other techniques for increasing the effective dynamic range of gray scale images include the removal of most significant bits in the intensity values of the image and in a histogram equalization process [7]. Figure 1 is an example of the former procedure where the wheels of the tank are made more readily apparent by removing the most two significant bits of the gray scales. The technique is quite common in digital image processing facilities for getting a quick idea of what is contained in an image plane.

Figure 2 is another example in which the histogram equalization procedure is demonstrated. Specifically a histogram of gray levels is a form of the original image. The image is then requantized to be as uniform in gray levels as possible. The technique can be interpreted as providing an equalization of energy for the viewer under the (possible erroneous) assumption that one does not like a heavily dark or light image. The results in
the figure indeed demonstrate that the tank behind the cheesecloth is more readily apparent in the equalized process.

**Conclusion**  This paper has casually discussed some of the applications of the digital computer to the manipulation of photographic quality images. Basically, image restoration and enhancement are objectives of such processes, the former being the correction of degradating phenomena in the image formation, and the latter being the optimization of images for human observation. While the two approaches have been presented as separate entities, they, of course, are heavily interactive. Mathematical models play a heavy role in the restoration process and are useful for describing enhancement procedures. The simple examples are presented as illustrative of the techniques of combined computer and image.

**References**


Fig. 1. Bit Removal
Fig. 2. Histogram Equalization