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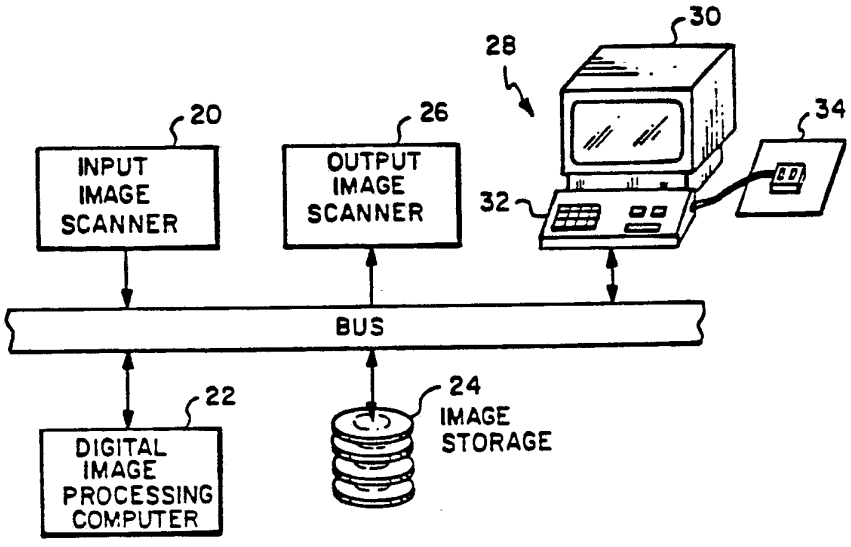

(57) Abstract

A block transform image sharpening method employs singular value decomposition to boost texture and edge detail while not boosting shaded (uniform) areas of the image characterized by a lower signal-to-noise ratio while at the same time reducing noise in other areas of the same image not containing much edge detail or texture.

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DIGITAL IMAGE SHARPENING METHOD USING SVD BLOCK TRANSFORM

Related Applications

This application contains subject matter related to PCT Patent Application Serial No. US88/00519 entitled "DIGITAL IMAGE NOISE SUPPRESSION METHOD USING SVD BLOCK TRASNFORM" filed February 22, 1988.

TECHNICAL FIELD OF THE INVENTION

The invention relates to block transform digital image processing methods for increasing the sharpness of a digital image.

Background of the Invention

The invention includes a noise suppression algorithm and a sharpening algorithm. The sharpening algorithm of the present invention is closely related to the noise suppression algorithm of the invention, since the success of these algorithms depends upon their ability to separate image detail from noise. Uniformly blurring the image (as in the prior art) achieves noise suppression, but unfortunately it also blurs image detail. Simple unsharp masking (as in the prior art) sharpens image detail but it also boosts noise. Hence, one goal of the invention is to distinguish image detail from noise while intelligently controlling the image components so as to perform both noise suppression and sharpening in the same image. The goal of the noise suppression algorithm of the invention is to suppress noise while leaving image detail untouched. The goal of the sharpening algorithm of the invention is to sharpen the image detail without boosting the noise.

In the present invention, the method used for noise suppression to discriminate image detail from noise is also employed to do the image sharpening, with appropriate modifications. A singular value decomposition (SVD) block transformation method has been shown in the related application referenced above to discriminate between image detail and noise, and is consequently used in the present invention to perform noise suppression. The same SVD noise suppression algorithm is employed in the invention with appropriate modifications to sharpen the image as well. For image sharpening, the invention does not need to work with the large block sizes disclosed in the related application. It is sufficient to use smaller block sizes (5x5 or 7x7 kernels).

Another embodiment of the invention includes the application of a non-linear gain function which will be described in detail later.

SUMMARY OF THE INVENTION

The present invention is a block transform image sharpening process. In arriving at the present invention, we found it helpful to consider the statistical properties of the noise being removed from an image, and the statistical properties of the image details such as texture and edges that were to be preserved in the processed image. In particular, we examined the statistical properties of the noise, and image detail in the transformed coordinate space. For a spatial transformation of the Walsh-Hadamard type, a transform coefficient of the noise is characterized by a Gaussian-like distribution around a mean value of zero. This is shown by Curve 10 in Fig. 2. The transform coefficients of the picture detail,

including edges and texture, form a Lapacian-like distribution, also centered about zero (shown by Curve 12 in Fig. 2.)

The transform coefficients from the picture detail have generally higher amplitude in absolute terms than the ones from the noise. Noise suppression is achieved by thresholding the transform coefficients or by modifying them through a non-linear gain function. This will remove most of the noise but unfortunately it will remove the low amplitude transform coefficients from the image detail which will create artifacts. The artifacts are most noticeable and objectionable in low contrast fine textured area.

We also examined the variance distributions of the image components such as noise, texture, and edges, and noted that there was a much better separation of the statistics of the image components when plotted against variance of small regions. Fig. 3 is a graph showing variance plotted against distribution (number of occurrences) for film grain noise (Curve 14), texture (Curve 16), and edge detail (Curve 18) for a typical digital image produced by scanning a photograph.

It will be appreciated from a comparison of Fig. 2 with Fig. 3, that a noise reduction technique that discriminates based upon the variances of image detail will have a much better chance of reducing noise without affecting texture extensively. We also came to realize that there exists an image transformation called singular value decomposition (SVD) that decomposes an image into a set of singular vectors and singular values that are closely analogous to the concept of principal component analysis in statistics. This can be

appreciated from the following analysis:

If an mxn matrix is treated as a set of n m-dimensional column vectors and the mean column vector is set to zero by subtracting it from every column vector of the matrix, then the singular values of the resulting matrix are the square roots of the variances of the m vector components in a rotated space. The rotated space is such that there is no correlation between any two components of the sample vectors in the rotated space. The distribution of the singular values for noise is a slowly decreasing function when they are ordered in decreasing order. The distribution of the singular values for the picture detail will be quite different from the noise. Also, the singular values for the picture detail will be much higher than those of the noise. And as mentioned above, discrimination of the noise from the picture detail will be much better.

According to the method of the present invention, a digital image is processed in a computer to increase sharpness by performing the following steps. First a non-linear gain function is produced, based upon the measured statistics of the singular values of the noise in the image. A detail image, and a low pass filtered image are produced from the digital image to be processed. The detail image is divided into blocks and the blocks are transformed into singular vectors and a diagonal array of singular values. The non-linear gain function is applied to the singular values to produce an array of singular values which have been modified so as to boost those regions of the detail image containing "edges" and characterized by a higher signal-to-noise ratio than other regions. An

inverse SVD transform is performed on the singular vectors and the modified singular values to produce blocks of processed detail image values. Finally, the processed detail image is added to the low pass image to generate a sharpened image.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram showing a digital image processing system suitable for practicing the method of the present invention;

Fig. 2 is a graph useful in describing the statistics of image features processed according to the prior art;

Fig. 3 is a graph useful in describing the statistical features of an image processed according to the present invention;

Fig. 4 is a block diagram illustrating the method of digital image processing according to the present invention;

Fig. 5 is a block diagram illustrating the step of generating the table of factors described in Fig. 4;

Fig. 6 is a graph showing the values of a typical table of factors generated according to the steps shown in Fig. 5;

Fig. 7 is a block diagram showing a block overlap method of processing a digital image according to the present invention;

Fig. 8 is a diagram useful for describing the image processing method shown in Fig. 7;

Fig. 9 is a block diagram showing a digital image processing method according to the present invention;

Figs. 10a-10c are diagrams showing the values of the coefficients employed in the digital filter shown in Fig. 9;

Fig. 11 is a diagram showing a digital image processing method according to the present invention employing block overlap and a spatial frequency band pass image signal;

Fig. 12 is a diagram showing a mode of practicing the invention including means for processing diagonal edge information; and

Fig. 13 is a diagram useful in describing the operation of the digital image processing method shown in Fig. 12.

MODES OF CARRYING OUT THE INVENTION

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The digital image signal referred to in the following description is generated by scanning and sampling an original image. For purposes of describing the preferred embodiments, the input signal is generated from a photographic negative or transparency. The digital image signal represents a variety of spatial components of the image, including an average brightness level, fine detail such as lines and textures, intermediate detail such as small features, and coarse details such as shading on smooth surfaces and other gradually varying features. In addition, the signal includes a noise component affecting most of the spatial components of the image to some degree.

With a photographic negative or transparency, much of the noise is film grain

noise. While the invention will be described in connection with sampled data from a photograph, it should be understood that the input signal can represent other information or data such as would be derived from directly scanning an object, from a composite video signal or from image information stored in optical or magnetic storage media. In such cases, the noise may originate in other characteristics of the image signal generating system. Since the singular values mentioned above measure correlations, the method of the invention can discriminate noise originating from a wide variety of noise sources so as to selectively sharpen "edge" features in the image while avoiding any "sharpening" of noise.

Fig. 1 is a schematic diagram showing a digital image processing facility useful for practicing the present invention. The digital image processing facility includes an input image scanner 20, such as a CCD scanner or a graphic arts flat bed or drum scanner. A digital image signal generated by an input scanner 20 is processed by the digital image processing computer 22. The digital image processing computer 22 can be a general purpose digital computer, or a special purpose computer specifically designed for processing images (e.g., a parallel multi-processor computer with 16 micro-processors and local memory). The original digital image from the scanner, and/or the processed digital image may be stored in a mass image storage memory 24, comprising for example magnetic or optical disk storage media.

The original and/or processed image may be displayed by means of an output image scanner 26, such as a CRT or laser film scanner. The system is

controlled by an operator from a work station 28 such as the Sun work station manufactured and sold by Sun Microsystems Inc. The work station includes a CRT 30 for temporarily displaying an image, a keyboard 32, and graphics input device such as a mouse and graphics tablet 34.

Fig. 4 is a block diagram showing the major steps implemented by the image processing computer 22 in carrying out one mode of digital image processing according to the present invention. A low pass digital filter (e.g. a 11x11 pixel Gaussian Filter) is applied (36) to the digital image signal Z to produce a low pass digital image signal G. The low pass digital image signal G is subtracted (38) from the suitably delayed digital image signal Z to produce a detail image signal H. The detail image signal H is processed, employing SVD transformation (40), as described in detail below to produce a selectively sharpened detail signal H'.

In the SVD process the detail image signal H is block SVD transformed (44), employing the well known SVD computer program listed in Appendix F attached hereto and described on pages 229 to 235 of the book: Computer Methods for Mathematical Computations by G. E. Forsythe, M. A. Malcolm, and C. B. Moler published by Prentice-Hall Inc., Englewood Cliffs, N.J., 1977, to produce singular vector matrices U,V^T, and a diagonal matrix D of singular values d_i arranged in order of descending amplitude where:

$$H = UDV^T \quad , \qquad (1)$$

where: H is an nxn sub block (e.g. 5x5 pixels) of the image,

U contains the eigenvectors of HH^T,

D is a diagonal matrix which contains

singular values d_1 $d_2 \ldots d_n$ in order of descending amplitude, and

V contains the eigenvectors of $H^T H$.

The singular values in the diagonal matrix (array) D are modified in a non-linear fashion (46) by respective individual factors f_i stored in look-up table (LUT) 48 to produce an array D' of modified singular values. The generation of the factors stored in the look-up table 48 will be described in more detail below. The array of modified singular values D' and singular vectors U, V^T are inversely transformed (50) to produce a selectively boosted detail signal H' which is then added to the low-pass filtered image G to produce a sharpened image Z'. It is the generation of the factors f_i which is the key to selectively boosting just those regions of the detail image containing edges or characterized by a higher signal-to-noise ratio than the other regions of the detail image.

The generation of the factors f_i from a non-linear gain function (52 in Fig. 4) will now be described with reference to Fig. 5. A digital noise image N generated for example by scanning a uniformly exposed and developed film is low pass filtered (54) for example by a 11 x 11 pixel Gaussian digital filter, to produce a low pass filtered noise image L.

The low pass filtered noise image L is subtracted (56) from the suitably delayed noise image N to produce a noise detail image signal. The noise detail image signal is block SVD transformed (58) to produce singular vectors and arrays of singular values d_i for the noise image blocks. The singular values d_i from each block of the

transformed noise detail image are accumulated and the means μ_i and standard deviations σ_i of the singular values in the respective positions of the array are calculated (60) as follows:

$$\mu_i = \frac{1}{n} \sum_{j=1}^{n} d_{i,j} \; ; \tag{2}$$

$$\sigma_i = \frac{1}{n} \sum_{j=1}^{n} (d_{i,j} - \mu_i)^2 \tag{3}$$

where i is an index for the order of singular values, and j is an index for different blocks.

A factor f_i for each singular value d_i is then generated (62) by considering the following facts. The singular values of the noise will be centered at μ_i with standard deviation σ_i. The singular values of the shading areas of the image (where little or no sharpening is desired) will have slightly higher values than those of the areas dominated by noise. The singular values of the textured areas of the image (where some sharpening is desired) will have even higher values depending on the texture. The singular values of the edges in the image (where the greatest sharpening is desired) will have much higher values than those of the noise.

Considering the above, each singular value d_i, is multiplied by a factor f_i through a non-linear function $F(d_i,\mu_i,\sigma_i)$ defined as below to produce the output singular value d'_i.

$$d'_i = f_i * d_i,$$

where

$$f_i = F(d_i,\mu_i,\sigma_i).$$

$$F(d_i,\mu_i,\sigma_i) = f_{min} + (f_{max}-f_{min})*(1-\exp[-a*(\frac{di-\mu i-thl*\sigma i}{\sigma_i})^p]),$$

if $d_i > (\mu_i + thl*\sigma_i)$;

$= f_{min}$, if $d_i < (\mu_i+thl*\sigma_i)$. (4)

f_{max} is a constant chosen for image sharpening and has a value (for example) in the range of one to three. f_{min} is a constant chosen for the desired noise discrimination, which has a value between zero and one. The parameters a, p, and thl are determined such that a good noise discrimination in the shading and textured area is achieved. The parameter thl controls a threshold level. The parameters a and p control the transition between f_{max} and f_{min}.

For noise suppression, one would have $f_{min} = 0$ and $f_{max} = 1$. For sharpening, $f_{min} = 1$ and $f_{max} = 3$, a choice which leaves noise as it is while boosting the image detail. By combining both features, for example selecting $f_{min} = 0$ and $f_{max} = 3$, one achieves sharpening with noise suppression. The noise suppression is not as good as that achieved using larger sized blocks or kernels (as disclosed in the above-referenced related application) but it does provide a second advantage in an algorithm which performs both noise suppression and sharpening simultaneously in the same image.

The formula mentioned above is only one form of many possible formulas that can be used as a factor for sharpening. From equation 4, the resulting behavior of f_i as a function of d_i is illustrated as a curve in Fig. 6. The effect is to threshold the noise, reduce the singular values for

shading area, and boost those singular values corresponding to texture and edges. The selection of thresholding level and curve shape depends on the artifacts one might tolerate.

The values f_i of the non-linear gain functions $F(d_i,\mu_i,\sigma_i)$ are calculated for each singular value d_i to produce a table of factors f_i for each singular value. The factors f_i are digitized in the form of look up tables and stored in look up table 48 shown in Fig. 4.

A Fortran program for implementing, in a general purpose digital computer, the basic SVD digital image processing method described with reference to Figs. 4 and 5 is listed in List 1 with reference to the attached appendices.

LIST 1

This is a basic version of the method which is described in Figs. 4 and 5.

1. Get a low pass filter ---filter.for....APPENDIX A
2. Convolve with a filter ---convol.for...APPENDIX B
3. Get a band-passed image---imgn.for.....APPENDIX C
4. Get SVD noise data ---svdnoi.for....APPENDIX D
5. Basic version of SVD ---svd_basic.for APPENDIX E
6. Subroutines for above programs ---svd_util.for..APPENDIX F

According to the presently preferred mode of practicing the invention, the block SVD processing is performed using a moving average technique employing block overlap to reduce the appearance of blocking artifacts. Fig. 7 is a

schematic block diagram showing the major steps involved in the block overlap SVD processing.

For the purpose of simplifying the description, processing incorporating a 4 x 4 pixel block, with a 2 pixel step in the horizontal and vertical directions will be described. Such a block overlap pattern is shown in Fig. 8. In the actual practice, a 5 x 5 pixel block is employed with 1 or more pixel steps, depending on the tolerance of the blocking artifacts. Referring to Fig. 7, an image detail signal H, generated as shown in Fig. 4, is processed by a block SVD process 40 (as shown in Fig. 4) to produce a processed image detail signal H_1'. Simultaneously, the image detail signal H is delayed by 2 pixels (64) and block SVD processed 40' to produce a processed image detail signal H_2'. The 2 pixel delay has the effect of shifting the blocks that are processed by 2 pixels, as shown by the blocks of pixels labeled 66 and 68 in Fig. 8. The image detail signal is similarly delayed by 2 lines (70), and 2 lines plus 2 pixels (72) and block SVD processed (40") and (40''') to produce processed image detail signals H_3' and H_4' respectively. The 2 line and 2 line plus 2 pixel delays have the effect of shifting the blocks as shown by the blocks of pixels labelled (74) and (76) respectively in Fig. 8. The processed detail signals H_1', H_2', H_3' and H_4' are registered, summed, and averaged (78) to produce the processed image detail signal H'. The processed image detail signal H' is added to the low pass filtered image signal G to produce the processed image signal Z' as shown in Fig. 4. It will be readily apparent that the processing method may be extended to larger blocks with different amounts of block overlap. A moving

average SVD Fortran program for implementing the processing method described with reference to Fig. 7 in a general purpose digital computer, is listed in List 2 with reference to the attached appendices.

LIST 2

This version of the method includes the block moving average described in Fig. 7.

1. SVD with moving average---svd_move.for..APPENDIX G
2. Subroutines.....---svd_util.for..APPENDIX F

Multistage processing is not necessary, although on a more complicated scheme one might want to boost different frequency bands differently. A processed image with only a single stage (as shown in Fig. 4) shows good results for most applications.

The SVD processing method according to the present invention can be extended to a processing method of the type disclosed in U.S. Patent No. 4,442,454 issued April 10, 1984 to Powell, wherein the processing employs a detail signal representing a pass band of spatial frequencies. The processed digital image signal is obtained, whereby noise from certain spatial frequency content is effectively removed from the image. As shown in Fig. 9 an input digital image Z is filtered through a 3 x 3 pixel low pass filter 80 to obtain the low pass filtered image S. S is subtracted from Z (82) to obtain the difference image Z-S which is a bandpass filtered version of image Z. The difference image signal Z-S is a bandpass version of the original image Z. The bandpass image is processed by the SVD process 40 to

determine the amount of image sharpening in each area of the image before being combined (92) with the low pass filtered image L to produce the sharpened Z'. The low pass filter coefficients used to produce the digital filters 80, 84 and 86 are shown in Fig. 10.

A Fortran program for implementing the multi-stage SVD digital image processing method described with reference to Fig. 9 in a general purpose digital computer, is listed in List 3 with reference to the attached appendices.

LIST 3

The basic SVD method applied to the multi-stage processing method described in Figs. 9 and 10.

1. Get the low pass filter ---sml_filter.for APPENDIX H
2. Convolve with a filter ---convol.for...APPENDIX B
3. Get a band-passed image---imgn.for.....APPENDIX C
4. Get SVD noise data ---svdnoi.for....APPENDIX D
5. SVD with moving average---basic.version of.svd_for....APPENDIX E
6. Subroutines for above programs ---svd_util.for..APPENDIX F

The moving average technique can be employed with the multi-stage method described with reference to Fig. 9 as follows. Instead of processing the Z-S image through SVD process 40, the bandpass image can be processed through the block-overlap SVD processing as described above with reference to Figures 7 and 8. The flow chart of

this combined processing is shown in Fig. 11. Referring to Fig. 11, a filter and difference amplifier 94 is employed to generate the bandpass image Z-S and a low pass image L from image Z as was described in Fig. 9. A block-overlap SVD process 96, as shown in Fig. 11, is applied to the bandpass signal Z-S to produce a processed bandpass image (Z-S)'. The processed bandpass image is summed (98) with low pass image L to produce processed image Z'.

A Fortran program for implementing the multi-stage, moving average SVD digital image processing method described with reference to Fig. 11, in a general purpose digital computer, is listed in List 4 with reference to the attached appendices.

LIST 4

This SVD method with the block moving average apply to multi-stage processing method described in Fig. 11.

1. Get the low pass filters (s, m, and l)
---sml_filter.for APPENDIX H
2. Convolve with a filter ---convol.for...APPENDIX B
3. Get a band-passed image---imgn.for.....APPENDIX C
4. Get SVD noise data ---svdnoi.for....APPENDIX D
5. SVD with moving average---svd_move.for..APPENDIX G
6. Subroutines for above programs ---svd_util.for..APPENDIX F

To improve the response to diagonal edges having ± 45° orientation, the image blocks are sampled in a trapezoidal pattern as shown in Fig. 13. In this figure, we show by example how (for

example) a 4 x 4 block of pixels $P_{n,m}$ can be sampled in three different grid orientations, -45° (shown by dotted lines), 0° (shown by solid lines), and +45 degrees (shown by dashed lines). Note that the three differently oriented sampling patterns have a sub-block of 4 common pixels ($P_{4,2}P_{5,2}P_{4,3}$ and $P_{5,3}$) in the center. As shown in Fig. 12, the SVD transform is performed on each of the three blocks of different orientations. The image detail signal H, generated as shown in Fig. 4, is processed by a 0° block SVD transform 44, +45° block SVD transform 44', and a -45° block SVD transform 44", to produce sets of singular vector matrices U and V^T and singular values d_i.

The singular values d_i are noise normalized (100, 102, 104) according to:

$$z_i = (d_i - \mu_i)/\sigma_i \qquad (5)$$

where i = 1, 2, ... n; and μ_i and σ_i are the mean and standard deviations, respectively of the noise singular values d_i, generated for each block orientation (0°, 45°, and -45°) as described previously with reference to Fig. 5. The block orientation most closely corresponding to the orientation of an edge is selected (106) on the basis of the values of the noise normalized singular value z_i. Generally, if the orientation of the SVD blocks transform corresponds to the orientation of an edge in the image, its noise normalized singular values z_i decrease faster as the index i increases, and the first few values z_1 and z_2 are higher than those of blocks not oriented with an edge.

The selection is performed as follows.

Starting from i=1, z_i from each block is compared with the noise level say $3.5\sigma_i$ for the block orientation. The lowest index i where the normalized singular value falls within the noise level is noted and denoted i_n. If i_n for all 3 block orientations (i.e., 0°, 45° and -45°) are each different, the block orientation with the lowest i_n is selected. If the lowest i_n is the same for two orientations, then the orientation with the largest value of $(z_1 + z_2)$ is selected. If i_n is identical for all three orientations, and i_n is 1, then the region is most likely dominated by noise, and the 0° orientation is selected. If i_n is the same for all three orientations and i_n is equal to 2, then the orientation with the largest value of z_1 is selected. If i_n is the same for all three orientations and i_n is greater than 2, then an orientation with the largest $(z_1 + z_2)$ is selected.

An orientation chosen in this way provides the best representation of the local image detail. A look up table 48 of factors f_i for modifying the singular values is prepared as was described with reference to Fig. 5 for each block orientation. The appropriate factors f_i are applied (46) to the singular values d_i from the block having the selected orientation to produce modified singular values d_i'. The modified singular values d_i' and singular vector matrices U and V^T are inverse transformed (50) to produce a sharpened image detail signal. The 4 pixels ($P_{4,2}P_{5,2}P_{4,3}$ and $P_{5,3}$) common to all three block orientations are extracted from each processed block to produce the sharpened image detail signal H'. Finally, the sharpened image detail signal H' is added back to

the low pass image signal G to form the processed image signal Z' as shown in Fig. 4. Although the diagonal block SVD processing method was described with reference to 4 x 4 block of pixels for ease of description, the presently preferred block size is 5 x 5 pixels.

The diagonal block SVD processing method is preferably implemented using the multi-stage block overlap technique described with reference to Fig. 11, and the center common block portion of 4 pixels is extracted from the SVD processed block of that orientation.

A Fortran program for implementing in a general purpose digital computer, the diagonal block SVD processing method described with reference to Fig. 12 is listed in List 5 with reference to the attached appendices.

LIST 5

This version of the method includes the block moving average and 3-orientation described in Fig. 12.

1. Get the low pass filter---filter.for....APPENDIX A
2. Convolve with a filter ---convol.for....APPENDIX B
3. Get a band-passed image---imgn.for.....APPENDIX C
4. Get SVD noise data ---svdnoi.for....APPENDIX D
5. SVD with moving average and and 3-orientations ---svd_move_3ori. for.....APPENDIX I
6. Subroutines for above programs ---svd_util.for..APPENDIX F

The method of the present invention can be

applied to processing digital color images in a variety of ways. In one mode, the digital color image is separated into red, green, and blue color separation images, and each color separation image is processed using a block SVD transform method as described above. In the preferred mode of practicing the invention with a color image, the red, green, and blue color image is transformed into a luminance Y (e.g. Y = 3/8 R + 4/8 G + 1/8 B) and two color difference components (R-Y and B-Y). Each of these images is processed using any one of the SVD block transform methods described above to produce processed luminance and color difference signals. The processed luminance and color difference signals are recombined to produce the processed color image. In an alternative method, the red, green, blue color images are transformed into a luminance (Y), and two color difference components (R-Y and B-Y). Only the luminance image Y is processed using the block SVD transform method and the processed luminance image is recombined with the color difference components to produce a processed color image. This approach reduces the processing time compared with the method discussed immediately above.

Industrial Applicability and Advantages

The image processing method according to the present invention is useful in graphic arts digital image processing and photographic digital image processing. The method has the advantages of producing a sharpened image, having reduced noise, and free from undesirable artifacts in areas of texture. The method has the further advantage that image detail is not perceptibly degraded by the sharpening process.

APPENDIX A


```
      c      filter.for
      c      generate filter(mask) file

      c      oct-26-87
      c      link with svd_util.for

      character*32 text,fname,fname2
      dimension table(0:999)

      data ir,iw/5,6/
      data iu,iu2/99,98/

      write(iw,10)
   10 format(/,' filter: generates filter file',/)

c     input

      text='filter file'
      call ascnam(ir,iw,text,fname)
      call blksiz(ir,iw,nbe,nbl)
      call smplxy(ir,iw,ixsmpl,iysmpl)

      write(iw,32)
   32 format(' mode options:'
     1,/,14x,'0:gauss'
     2,/,14x,'1:exp'
     3,/,14x,'2:uniform'
     4,/,14x,'3:user input'
     5,/,14x,'4:input from disk, ascii file'
     1,/,' mode, sigma_x,sigma_y')
      read(ir,*) mode,sigmax,sigmay
```

```
      34     format(1,2f)

      c      user input mask

             if(mode.eq.3) then
             write(iw,112)
      112    format(' type line by line: max 10x10 by hand
                    input')
             do 801 j=0,nbl-1
             write(iw,114) j
      114    format(1x,i5,' th line ?')
             read(ir,*) (table(j*nbe+1),i=0,nbe-1)
      116    format(10f)
      801    continue
      c      enddo   loop j

             else if(mode.eq.4) then
             call clrasc(32,text)
             text='user input disk file'
             call ascnam(ir,iw,text,fname2)
             open(unit=iu2,file=fname2,status='old')
             read(iu,*) nbe,nbl,ixsmpl,iysmpl
      216    format(4i)
             do 802 j=0,nbl-1
             read(iu,*) (table(j*nbe+1),i=0,nbe-1)
      218    format(10f)
      802    continue
      c      enddo   loop j

             else if(mode.eq.0.or.mode.eq.1.or.mode.eq.2)
                    then

             xc=(nbe-1)/2.
             yc=(nbl-1)/2.
```

```
                do 803 iy=0,nbl-1
                do 804 ix=0,nbe-1

                x=float(ix)-xc
                y=float(iy)-yc

      c         gaussian,exponential,and uniform masks

                if(mode.eq.0) then
                table(iy*nbe+ix)=gauss(x,sigmax)*gauss
                        (y,sigmay)
                else if(mode.eq.1) then
                table(iy*nbe+ix)=exp(-abs(x)/sigmax)*
                         exp(-abs(y)/sigmay)
                else if(mode.eq.2) then
                table(iy*nbe+ix)=1.
                endif
      c         mode

      804       continue
      c         enddo   loop ix
      803       continue
      c         enddo   loop iy

                endif
      c         mode

      c         output
               open (unit=iu,file=fname,status='new')

                write(iu,102) nbe,nbl,ixsmpl,iysmpl,sigmax,
                        sigmay
      102       format(1x,4i5,2e15.5)
               do 805 i=0,nbe*nbl-1
                write(iu,104) i,table(i)
```

```
      104   format(1x,i5,e15.5)
      805   continue
      c     enddo

            close(iu)

           end


            function gauss(x,sigma)

            data pi/3.1415926535/

            if(sigma.eq.0.) then
                    if(x.eq.0.) then
                    gauss=1.
                    else if(x.ne.0.) then
                    gauss=0.
                    endif
            else if(sigma.ne.0.) then
                    arg=(x**2)/(2.*(sigma**2))
                    gauss=exp(-arg)/(sqrt(2.*pi)*sigma)
            endif

            return
            end
```

APPENDIX B


```
      c     convol.for
      c     convolution of an image with a mask(filter)

      c     oct-26-87
      c     link with svd_util.for

      c     assumes picture is one layer

            character*1 com
            character*32 fname1,fmask,fname3
            character*32 text

            dimension bufi(0.99999)
            dimension bufo(0:1999)
            dimension work1(0:2100),work2(0:2100)
            dimension lp(0:59)
            dimension wt(0:899)

            data ir,iw/5,6/
            data iu1,iu2,iu3/51,52,53/

      c     ne: number of pixels per line (max:2000
                  pixels)
      c     nl: number of lines of the image
      c     nbe: # of elements per block (block size in x)
      c     nbl: # of lines per block (block size in y)

            write(iw,10)
      10    format(/,' convol: makes a convolution of an
                  image',/)
```

```
      call picsiz(ir,iw,'i',nc,ne,nl)
      call recsiz(ir,iw,ne,lform,lrec)
      call winsiz(ir,iw,ne,nl,ixl,ixh,iyl,iyh)
      call picnam(ir,iw,1,'i',fname1)
      call picopn(iul,fname1,lrec,'old',' ')
c     input file seqeuntial

      text='convolution mask file'

      call ascopn(iu2,fmask,'old',' ')
c     readonly

      call picnam(ir,iw,1,'o',fname3)
      call picopn(iu3,fname3,lrec,'new',' ')

      write(iw,52)
52    format(' normalization by sum of masks
     +        (y:d/n) ?')
      read(ir,54) com
54    format(a1)

      read(iu2,*) nbe,nbl,ixsmpl,iysmpl,dum,dum
114   format(1x,4i5,2e15.5)
      do 801 j=0,nbl-1
            do 802 i=0,nbe-1
            k=j*nbe+1
            read(iu2,116) iorder,wt(k)
            write(iw,118) iorder,wt(k)
116   format(1x,i5,e15.5)
118   format(ix,i5,'th weight = ',e15.5)
802   continue
c     enddo   loop i
801   continue
c     enddo       loop j
```

```
      close(iu2)

      sum=0.

      do 803 k=0,nbe*nbl-1
      sum=sum+wt(k)
803   continue
c     enddo    loop k

      nbec=(nbe-1)*ixsmpl/2
c             !center of nbe
      nblc=(nbl-1)*iysmpl/2
             !center of nbl
      msizx=ixsmpl*(nbe-1)+1
      msizy=iysmpl*(nbl-1)+1
      nbsizx=ixsmpl*nbe
      nbsizy=iysmpl*nbl

      write(iw,202) ix0,iy0,ixsmpl,iysmpl
     1,msizx,msizy,nbsizx,nbsizy
202   format(' main: ix0,iy0 = ',2i8
     1,/,' main: ixsmpl,iysmpl = ',2i8
     1,/,' main: support size = ',2i8
     1,/,' main: nbe*ixsmpl,nbl*iysmpl = ',2i8)

      write(iw,*) 'ok '

c     let's take care of the border area here

      do 810 iy=1,jy0+nblc
c     do not bother to do (jy0+nblc-1) lines
      irec=iy
      read(iu1,rec=irec) (bufi(i),i=0,ne-1)
      write(iu3,rec=irec) (bufi(i),i=0,ne-1)
c     same one back
```

```
      810   continue
      c     enddo   loop iy

            lextra=0
            do 811 iys=0,iysmpl-1
            jy0=iy0+iys
            nytry=(nl-jy0-(nbl-1)*iysmpl)/iysmpl
      c     number of loops in y direction

            ll=nl-nytry*iysmpl-jy0-nblc
      c             remaining extra lines
            if(ll.gt.lextra) lextra=ll
      811   continue
      c     enddo   loop iys

      c     write out remaining lines

            if(lextra.gt.0) then
                    line3=nl-lextra+1

      c     starting line for lextra
                    do 812 iy=0,lextra-1
                    irec=line3+iy
                    read(iul,rec=irec) (bufi(i),i=0,ne-1)
                    write(iu3,rec=irec) (bufi(i),i=0,ne-1)
      812   continue
      c             enddo    loop iy
            endif
      c     lextra

      c     ok now run the engine

            do 820 iys=0,iysmpl-1
            jy0=iy0+iys
            jx0=ix0
```

```
            mseq=iys

            call engine(ir,iw,iul,iu3,ne,nl,nbe,nbl,
     5                  ixsmpl,iysmpl
           1,bufi,bufo,lp,workl,work2
           2,jx0,jy0,mseq,wt,nbsizx,nbsizy,nbec,nblc,lrec)

        820 continue
    10  c   enddo  loop iys

        c   normalize by the sum of weights

            if(com.eq.'n'.or.com.eq.'N') then
    15      write(iw,*) ' as you chose, the normalization
                        was not done. '
            else
            denom=sum
            call dskdiv(iu3,iu3,lrec,bufi,ne,nl,denom)
    20      endif
        c   !com

            close(iul)
            close(iu3)
    25
            end

        c-------------------------------------------------

    30      subroutine engine(ir,iw,iul,iu3,ne,nl,nbe,nbl,
                        ixsmpl,iysmpl
           1,bufi,bujo,lp,workl,work2
           2,jx0,jy0,mseq,wt,nbsizx,nbsizy,nbec,nblc,lrec)

    35      dimension bufi(0:ne*nbl-1)
```

```
      c       for nbl lines
              dimension bufo(0:ne-1)
                      output buffer
              dimension lp(0:nbl-1)
              dimension work1(0:ne+nbe-2)
              dimension work2(0:ne-1)
              dimension wt(0:nbe*nbl-1)

              if(mseq.eq.0) then
              write(iw,802) nbe,nbl,ixsmpl,iysmpl
      802     format(' engine: nbe,nbl,ixsmpl,iysmpl=',4i5)
              write(iw,804)
      804     format(' weights:')
              do 901 k=0,nbe*nbl-1
              write(iw,806) k,wt(k)
      806     format(1x,i5,e15.5)
      901     continue
      c       enddo    loop k

              endif

              nytry=(nl-jy0-(nbl-1)*iysmpl)/iysmpl
      c       number of loops in y direction

              write(iw,800) jx0,jy0,nytry
      800     format(/,' engine: jx0,jy0,nytry:',3i5)

              call ptr0(nbl,lp)
      c       initialize pointer lp(k)

      c       initially read in nbl lines
              do 910 j=0,nbl-1
              linei=jy0+j*iysmpl+1
      c               irec starts from 1
              read(iul,rec=linei)
```

```
                    (bufi(ne*lp(j)+i),i=0,ne-1)

      910   continue
      c     enddo   loop j
 5
            linel=jy0+(nbl-1)*iysmpl+1
      c             offset for input  line
            linell=jy0+nblc+1
      c     offset for output line
10
            do 911 iy=0,nytry-1

            linei=linel+iy*iysmpl
      c     !iysmpl
15          if(iy.ne.0) then
            read(iul,rec=linei) (bufi(ne*lp(nbl-1)+i),
                        i=0,ne-1)
      c             always read into lp(nbl-1)
            endif
20    c     iy

            do 912 ixs=0,ixsmpl-1
            ixoff=jx0+ixs
            nxtry=(ne-jx0-ixs)/ixsmpl
25    c     number of data in x

      c------beginning of convolution calculation

            call clr(nxtry+nbe-1,work1)
30    c     clear working area
            call clr(nxtry,work2)
      c     temporaty place to hold sampled result

            nbec=(nbe-1)/2
35          do 913 j=0,nbl-1
```

```
            call movxs(nxtry,ixsmpl,bufi(ne*lp(j)+ixoff),
                  workl(nbec))

      c     get data into the working area with offset
            nbec
                  do 914 i=0,nbe-1
                  k=j*nbe+1
                  wtij=wt(k)
                  call mulcy(nxtry,wtij,workl(i),work2)

      c                 accumulate result in work2
      914   continue
      c           enddo   loop i

            call movxsi(nxtry,ixsmpl,work2,bufo(ixoff))
      c           get sampled output from the
                  convolution result

      913   continue
      c     enddo    loop j

      c------end of convolution calculation

      912   continue
      c     enddo    loop ixs

            lineo=linell+iy*iysmpl
            write(iu3,rec=lineo) (bufo(i),i=0,ne-1)

            call ptr(nbl,lp)
      c     update pointer

      911   continue
      c     enddo    loop iy
```

```
return
end
```

APPENDIX C


```
      c     imgn.for
      c     arithmatic operations:(add/subtract,multiply,
                  and divide)
      c     in n image layers

      c     sep-2-87
      c     link with iputil.for

      c     assumes picture is a one layer image.

            character*1 com
            character*32 fname(0:9)

            dimension buf(0:3999,0:9)
            dimension iu(0:9)
            dimension f(0:9)

            data ir,iw/5,6/
            data iu0/50/
      c     starting unit number

      c     ne: number of pixels per line
      c     nl: number of lines of the image
      c     n:  number of input files

            write(iw,10)
      10    format(/,' imgn: arithmatic in n image
                  layers',/)
            call picsiz(ir,iw,'i',nc,ne,nl)
            call recsiz(ir,iw,ne,lform,lrec)
            call winsiz(ir,iw,ne,nl,ixl,ixh,iyl,iyh)
```

```
                write(iw,22)
      22        format(' how many images as an input (max=9)
                       ?')
       5        read(ir,") n
      24        format(i)

                do 801 ifile=0,n
                iu(ifile)=iu0+ifile
      801       continue
      c         assign unit number

                call picnam(ir,iw,n,'i',fname(1))

      c         read n input file names starting fname(1)

                do 803 ifile=1,n
                call picopn(iu(ifile),fname(ifile),
                       lrec,'old',' ')
      803       continue
      c         enddo    loop ifile

                call picnam(ir,iw,1,'o',fname(0))
      c         output file

                call picopn(iu(0),fname(0),lrec,'new',' ')

                write(iw,52)
      52        format(' a(add),m(mul),d(div) ?')
                read(ir,54) com
      54        format(a1)

                do 804 i=1,n
                write(iw,56) i
      56        format(1x,i5,' th factor (real) ?')
```

```
            read(ir,*) f(i)
      58    format(f)
      804   continue

 5    c     enddo   loop i

      60    write(iw,62)
      62    format(' overall normalizationn factor
                  (real) ?')
 10         read(ir,*) f(0)
      64    format(f)
            if(f(0).eq.0.) go to 60

            call engine(ir,iw,iu,lrec,fname
 15       1,ne,nl,ixl,ixh,ihl,iyh,buf,n,f,com)

            do 821 ifile=0,n
            close(iu(ifile))
      821   continue
 20   c     enddo   !loop ifile

            end

      c-----------------------------------------------
 25

            subroutine engine(ir,iw,iu,lrec,fname
           1,ne,nl,ixl,ihx,ihl,iyh,buf,n,f,com)

            character*1 com
 30         character*32 fname(0:n)
            dimension buf (0:ne-1,0:n),iu(0:n),f(0:n)

            write(iw,12) com,n
      12    format(' engine: com,n =',a1,i5)
 35
```

```
                do 801 i=1,n
                write(iw,14) f(i)
          14    format(9x),'f(i) = ',t35,e15.5)
          801   continue
      5   c     enddo   loop i

                write(iw,16) f(0)
          16    format(,9x,'overall normalization =',e15.5)
                write(iw,705) ix1,ixh,iy1,iyh
     10   705   format(' ix1,ixh,iy1,iyh = ',4i5)

                do 802 iy=iy1+1,iyh+1
          c     since irec starts from 1

     15         do 803 ifile=1,n
                read(iu(ifile),rec=iy) (buf(i,ifile),i=0,ne-1)
          803   continue
          c     enddo   loop ifile

     20         do 804 ix=ix1,ixh
                buf(ix,0)=f(1)*buf(ix,1)
          804   continue
          c     enddo   !loop ix

     25         do 805 ifile=2,n
                if(com.eq.'1'.or.com.eq.'A') then
                           do 811 ix=ix1,ixh
                           buf(ix,0)=buf(ix,0)+f(ifile)*buf
                              (ix,ifile)
     30   811              continue
          c                enddo    loop ix
               else if(com.eq.'m'.or.com.eq.'M') then
                           do 812 ix=ix1,ixh
                           buf(ix,0)=buf(ix,0)*f(ifile)*buf
     35                       (ix,ifile)
```

```
      812                continue
      c                  enddo    loop ix
               else if(com.eq.'d'.or.com.eq.'D') then
                         do 813 ix-ixl,ixh
 5                       if(f(ifile)*buf(ix,ifile).ne.0.)
                             then
                         buf(ix,0)=buf(ix,0)/(f(ifile)*buf
                             (ix,ifile))
                         endif
10    c                  divide by zero ?

      813                continue
      c                  enddo    loop ix
               endif
15    c       com

      805      continue
      c        enddo    !loop ifile

20             do 806 ix=ixl,ixh
               buf(ix,0)=buf(ix,0)/f(0)
      806      continue
      c        enddo    loop ix

25             write(iu(0),rec=iy) (buf(ix,0),ix=0,ne-1)

      802      continue
      c        enddo          loop iy

30             return
               end
```

35

APPENDIX D


```
      c     svdnoi.for
      c     calculate svd distribution for a noise patch

      c     oct-26-87
      c     link with svd_util.for

      c     this program includes the mode options

      c     get a random block starting (ix0,iy0)
      c     input band-pass noise patch (random file)
      c     output : block size,ixsmpl,iysmpl
      c                order,mean svd,sigma svd,ratio

      c     block size up to 40x40

      character*32 text,fname1,fname2

      dimension  buf(0:1999,0:39)
      dimension  a(0:39,0:39),u(0:39,0:39),
     1           v(0:39,0:39)

      data ir,iw/5,6/
      data iu1,iu2/51,52/

      c     nbe: # of elements per block  (block size)
      c     ne: number of pixels per linbe (e.g. 400
     1           pixels, or 1136 pixels)
      c     nl: number of linbes of the image

      write(iw,10)
10    format(/' svdnoi: calculate svd distribution
```

```
      for a noise patch'/)

      call picsiz(ir,iw,'i',nc,ne,nl)
      call recsiz(ir,iw,ne,lform,lrec)
      call picnam(ir,iw,1,'i',fname1)
      call picopn(iul,fname1,lrec,'old',' ')

      call blksiz(ir,iw,nbe,nbl)
      call smplxy(ir,iw,ixsmpl,iysmpl)
      nbsize=nbe*ixsmpl

      text='output mean svd file'
      call ascnam(ir,iw,text,fname2)
      call ascopn(iu2,fname2,'new',' ')

      write (iw,122)
122   format(' mode'
     1,/,t25,'0: 0  degree or 90 degree'
     2,/,t25,'1: 45 degree'
     3,/,t25,'2: 135 degree')
      write(iw,110)
110   format(' mode ?')
      read(ir,*) mode
111   format(i)

      write(iw,140)
140   format(' ix0,iy0,nxtry,nytry ?')
      read(ir,*) ix0,iy0,nxtry,nytry
142   format(4i)

      call hui(ir,iw,iul,lrec,buf,nc,ne,nl,a,u,v
     1,nbe,ixsmpl,iysmpl,nbsize,ix0,iy0,nxtry,nytry,
          mode 2,iu2,fname1,fname2)

      close(iul)
```

```
      close(iu2)

      end

c-----------------------------------------------------

      subroutine hui(ir,iw,iul,lrec,buf,nc,ne,nl,
     a,u,v
     1,nbe,ixsmpl,iysmpl,nbsize,ix0,iy0,nxtry,nytry,
     mode
     2,iu2,fname1,fname2)

c     this subroutinbe does all the actual
      processing.
c     main program just sets up array sizes for a
      given picture.

      character*32 fname1,fname2

      dimension  buf(0:ne-1,0:nbe-1)
      dimension  a(0:nbe-1,0:nbe-1)
      dimension  u(0:nbe-1,0:nbe-1),v(0:nbe-1,
     0:nbe-1)

      dimension  work(100)
      dimension  sigma(0:39),id(0:39)
      dimension  fmean(0:39),fsigma(0:39),
     ratio(0:39)

      dimension  fsum1(0:39),fsum2(0:39)

c     parameters for svd subroutinbe
      n=nbe
      m=nbe
      nm=nbe
```

```
            ftot=nxtry*nytry
            ftot=ftot*ixsmpl*iysmpl

            call clrx(nbe+1,fmean)

      c     last of nbe for sum of singular values
            call clrx(nbe+1,fsigma)
            call clrx(nbe+1,fsum1)
            call clrx(nbe+1,fsum2)

            write(iw,800) mode,ix0,iy0,nxtry,nytry
           1,nbe,ixsmpl,iysmpl,nbsize
      800   format(' hui: mode,ix0,iy0,nxtry,nytry =
                  ',5i5,/
           1,6x,'nbe,ixsmpl,iysmpl,nbsize = ',4i5)

            ln=iy0

      c     skip (iy0-1) lines

            do 901 iy=0,nytry-1
      c     number of loops in y direction
            line1=iy0+iy*nbsize+1

            do 902 iys=0,iysmpl-1
            line2=line1+iys

                  do 903 j=0,nbe-1
      c     read nbe linbes
                  irec=line2+j*iysmpl
                  read(iu1,rec=irec) (buf(i,j),i=0,
                     ne-1)
      c     just read ne elements
      903   continue
```

```
      c                    enddo                loop nbe

                  do 904 ix=0,nxtry-1
                              number of loops in x direction
      5
                  ixoff1=ix0+nbsize*ix
                  if(mode.eq.1) then
                              ixoff1=ixoff1+nbsize/2
                  else if(mode.eq.2) then
      10                      ixoff1=ixoff1=nbsize/2
                  endif

                  do 905 ixs=0,ixsmpl-1
                  ixoff2=ixoff1+ixs
      15
                              do 906 j=0,nbe-1
            c     get a block into a(k,j)
                              do 907 k=0,nbe-1
                              kk=ixoff2+k*ixsmpl
      20                      if(mode.eq.0)then
                              a(k,j)=buf(kk,j)
            c     straight
                              else if(mode.eq.1)then
                              a(k,j)=buf(kk-j,j)
      25    c     45 degree slant
                              else if(mode.eq.2)then
                              a(k,j)=buf(kk+j,j)
            c     135 degree slant
                              endif
      30    c     mode?
            907   continue
            906   continue
            c                 end of loop j
            c                 end of loop k
      35
```

```
      call svd(nm,m,n,a,sigma,.false.,u,.false.,
     *        v,ierr,work)
      c       no need to calculate U and V matrix. so the
     *        input is .false.

      if(ierr.ne.0) write(iw,20) ierr,line2,ixoff2
   20 format(' trouble. ierr= ',i4,' at line2,ixoff2
     *        = ',2i5)

      call sort(nbe,sigma,id)
      c       sort in descending order

      c       sigma(i,l(id)): ith singular value

                    toteig=0.
      c             sum of eigen values
                    do 911 l=1,nbe-1
                    toteig=toteig+sigma(l)
  911 continue
      c             end of loop l

                    do 912 l=0,nbe
                    if(l.eq.nbe) then
                    fsuml(l)=fsuml(l)+toteig
                    fsum2(l)=fsum2(l)+toteig**2
                    else
                    fsuml(l)=fsuml(l)+sigma(l)
                    fsum2(l)=fsum2(l)+sigma(l)**2
                    endif
  912 continue
      c       end of loop l

  905 continue
      c       end of loop ixs
  904 continue
```

```
      c      end of loop ix

      902    continue
      c      end of loop iys
      901    continue
      c      end of loop iy

             ok now calculate statistics

             write(iw,100)
      100    format(3x,1,10x,'fmean',10x,'fsigma')

             do 913 l=0,nbe
             fmean(l)=fsuml(l)/ftot
             fsigma(l)=fsum2(l)/ftot-fmean(l)**2
                      if(fsigma(l).lt.0.) then
                      write(5,105) l,fmean(l),fsigma(l)
                      fsigma(l)=0.
                      endif
      105    format(' l,fmean(l),fsigma(l) = ',i5,2e15.5)

             fsigma(l)=sqrt(fsigma(l))

             if(fsigma(l).eq.0.) then
             ratio(l)=0.
             else
             ratio(l)=fmean(l)/fsigma(l)
             endif
      c      fsigma(l) ?

      913    continue
      c      end of loop l

             write(iu2,108) nbe,ixsmpl,iysmpl
      108    format(1x,3i10)
```

```
      do 921 l=0,nbe
c     write final result
      if(l.eq.nbe) then
      write(iw,110) fmean(l),fsigma(l),ratio(l)
      write(iu2,110) fmean(l),fsigma(l),ratio(l)
110   format(//,6x,3e15.5)
      else
      write(iw,120) l,fmean(l),fsigma(l),ratio(l)
      write(iu2,120) l,fmean(l),fsigma(l),ratio(l)
120   format(1x,i5,3e15.5)
      endif
921   continue
c     enddo

      write(iu2,130) fname2,fname1
130   format(/' svd noise file name = ',a32
     1,/,' from data file: ',a32)

      write(iu2,140) nc,ne,nl
140   format(//,' input parameters were: nc,ne,nl =
     1          ',3i5)
      write(iu2,150) nbe,ixsmpl,iysmpl,mode,ix0,iy0,
     1          nxtry,nytry
150   format(' nbe,ixsmpl,iysmpl = ',3i5
     1,/,' mode,ix0,iy0,nxtry,nytry = ',5i5)

      return
      end
```

APPENDIX E


```
      c     SHARPENING AND NOISE SUPPRESSION BY SINGULAR
            VALUE DECOMPOSITION

      c     SVD_BASIC.FOR -- BASIC VERSION

      C         link with svd_util.for

      C     DEC-20-88

      C     maximum svd block size : 0x40

            dimension BUFI(0:1999,0:39)
            dimension BUFO(0:1999,0:39)
            dimension A(0:39,0:39),U(0:39,0:39),
                    V(0:39,0:39)
            dimension WT(0:39)
            dimension FC(0:39),DFC(0:39),RATIO(0:39)

            data IR,IW/5,6/

            data iui,iuo,iun/51,52,53/
            data iuw/61/
            data a,u,v/1600*0.,1600*0.,1600*0./
            data wt/40*0./
            data fc,dfc,ratio/40*0.,40*0.,40*0./

      C     NBE: # of elements per block (BLOCK SIZE)
      C     NE: number of pixels per line(e.g. 500 pixels)
      C     NL: number of lines of the image
      c     ixsmpl,iysmpl : sampling in x and y directions
```

```
      C     INPUT

      c     define image size : nc,ne,nl
      5     call picsiz (ir,iw,'I',nc,ne,nl)

      c     define image record size
            call recsiz (ir,iw,ne,lform,lrec)

     10   c     open input image file
            call ifile (ir,iw,iui,lform,lrec)

      c     read noise data file
            call nfile (ir,iw,iun,nbe,ixsmpl,iysmpl,fc,
     15                   dfc,ratio)

      c     open output image file
            call ofile (ir,iw,iuo,lform,lrec)

     20   c     get pre/post processing weights
            call wfile (ir,iw,iuw,modew,nbe,wt,sum )

            write (iw,122)
          122   format (' Starting pixel position: IXO,IYO ?')
     25     read (ir,*) ix0,iy0

      c     block orientation mode = 0 (0 or 90 degree)

            modeb=0
     30
            write (iw,151)
          151   format (' Boost formula'
           3,/,' 6: THRESHOLD1 ,EXP(-A*X**4) AND FMIN,FMAX')

     35     write (iw,152)
```

```
      152    format (' Boost formula(I) ?')
             read (ir,*) iform

             write (iw,162)
      162    format (' THRSH1(R),POWER(R),FMIN,FMAX,
                     COEFF(FOR 6:) ?')
             read (ir,*) thrshl,power,fmin,fmax,coeff

             msize = ixsmpl*(nbe-1)+1
             nbsize = ixsmpl*nbe

             write (iw,202) nbe,ix0,iy0,ixsmpl,iysmpl,
                     msize,nbsize
      202    format (' MAIN: NBE,IX0,IY0 = ',T30,3I8
     1,/,' MAIN: IXSMPL,IYSMPL = ',T30,2I8
     2,/,' MAIN: SUPPORT SIZE = ',T30,I8
     3,/,' MAIN: NBE*IXSMPL = ',T30,I8)
      204    format (' MODEW, SUM OF WEIGHTS = ',I5,E15.5)

             if (modew.ne.0) then
                write (iw,204) modew,sum
             endif

                  jy0 = iy0
                  jx0 = ix0

                  call hui (ir,iw,iui,iuo,nc,ne,nl,nbe,
                     ixsmpl,iysmpl
            1           ,bufi,bufo,a,u,v,fc,dfc,ratio
            2           ,iform,thrshl,coeff,power,fmin,fmax
            3           ,jx0,jy0,modew,wt,lrec)

             if (modew.eq.1.or.modew.eq.2) then
                denom = (sum*sum)/(nbe*nbe)
                call dskdiv (iuo,iuo,lrec,bufo,ne,nl,denom)
```

```
      endif
c     close (iui)
c     close (iuo)

      end

c-----------------------------------------------------

      subroutine hui(ir,iw,iui,iuo,nc,ne,nl,nbe,
     1          ixsmpl,iysmpl
     1     ,bufi,bufo,a,u,v,fc,dfc,ratio
     2     ,iform,thrshl,coeff,power,fmin,fmax
     3     ,jx0,jy0,modew,wt,lrec)

C    THIS SUBROUTINE DOES ALL THE ACTUAL PROCESSING.
C    MAIN PROGRAM JUST SETS UP ARRAY SIZES FOR A
          GIVEN PICTURE.

      dimension  bufi(0:ne-1,0:nbe-1)
      dimension  bufo(0:ne-1,0:nbe-1)
      dimension  a(0:nbe-1,0:nbe-1)
      dimension  u(0:nbe-1,0:nbe-1),
                    v(0:nbe-1,0:nbe-1)
      dimension  work(100)
      dimension  fc(0:39),dfc(0:39),ratio(0:39)
      dimension  id(0:39),sigma(0:39)
      dimension  wt(0:nbe-1)

      n      = nbe
      m      = nbe
      nm     = nbe
      nbrxs  = nbe*ixsmpl

      nxtry  = (ne-jx0-nbe)/nbrxs-1
      nytry  = (nl=jy0-nbe)/nbrxs
```

```
            if (((nytry-1)*nbrxs +nbe).gt.nl) then
                nytry = nytry-1
            endif
            lextra = nl-nytry*nbrxs-jy0

      5

            write (iw,802) nbe,ixsmpl,iysmpl
           1 ,iform,thrshl,power,fmin,fmax,coeff
          802   format(' HUI: nbe,ixsmpl,iysmpl= ',3i5,/
           1  ' boost formula,thrshl,power,fmin,fmax,
     10              coeff = '
           2 ,/,1x,I5,5E15.5)
            write (iw,835) jx0,jy0,nxtry,nytry
          835   format (/,' HUI: jx0,jy0,nxtry,nytry',4i5)

     15   c     skip jy0 lines

            if (jy0.ge.1)then
               do 840, iy = 0,jy0 -1
               irec = iy+1
     20        read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
               write (iu0,rec=irec) (bufi(i,0),i=0,ne-1)
          840  continue
           endif
          c    processing the input image block by block
     25
           do 910, iy = 0,nytry-1
             line1 = jy0+1+iy*nbrxs

             do 910, iys = 0,iysmpl-1
     30        line2 = line1+iys

          c    read in nbe lines from the input image into
                 bufi
           do 850, j = 0,nbe-1
     35        linei = line2+j *iysmpl
```

```
            read (iui,rec=linei) (bufi(i,j),i=0,ne-1)

      c     initialize the output buffer -- bufo

            do 845, jj = 0,nbe-1
            do 845, ii = 0,ne-1
            bufo(ii,jj) = 0.
      845   continue
      850   continue

      c     set up array A(i,j)

            do 900, ix = 0,nxtry-1
              ixoff1 = jx0 +nbrxs*ix

              do 900, ixs = 0,ixsmpl-1
                ixoff2 = ixoff1+ixs+(nbe/2)*ixsmpl
                    do 860, j = 0,nbe-1
                    do 860, i = 0,nbe-1
                    ii = ixoff2+i*ixsmpl
                    a(i,j) = bufi(ii,j)
      860           continue
                    call svd (nm,m,n,a,sigma,.true.,u,
                        .true.,v,ierr,work)

             if (ierr.ne.0) then
                    write (iw,20) ix,iy,ierr
      20            format (' TROUBLE. IX,IY,IERR= ',3I6)
                    do 865, l = 0,nbe-1
                      write (iw,22) l,sigma(l)
      22              format (1x,i3,'th singular value =
                          ',E15.5)
      865           continue
                    do 866 i=0,ierr-1
                    sigma(i)=0.
```

```
      866          continue
                 endif

      c       sort sigma(==singular values) in descending
     5           order

                 call sort (nbe,sigma,id)

      c       SIGMA(I,L(ID)): Ith SINGULAR VALUE
     10

      C       COMPUTE NEW A(I,J) ACCORDING TO CORING
      C       FORMULAR(IFORM) FROM SIGMA, U, AND V.
                call newaij (ir,iw,nbe,id,a,sigma,u,v,fc,
                     dfc,ratio
     15         1       ,iform,thrshl,coeff,power,fmin,fmax)

                if (modew.eq.-1) then
                   do 885, j = 0,nbe-1
                   do 885, i = 0,nbe-1
     20              a(i,j) = a(i,j)/wt(i)/wt(j)
      885          continue
                else if (modew.eq.1) then
                   do 890, j = 0,nbe-1
                   do 890, i = 0,nbe-1
     25              a(i,j) = a(i,j)*wt(i)*wt(j)
      890          continue
                endif

      C       UPDATE OUTPUT BUFFER : BUFO
     30

                do 895, j = 0,nbe-1
                jj =j
                   do 895, i = 0,nbe-1
                   ii =ixoff2+i*ixsmpl
     35            bufo(ii,jj) = bufo(ii,jj)+a(i,jj)
```

```
      895      continue

      900    continue

C     WRITE LINES OUT TO DISK (AFTER NN LINES, MM
       BLOCKS ARE PROCESSED)

         do 905, j =0,nbe-1
            lineo = line2+j*iysmpl
            write (iuo,rec=lineo) (bufo(i,j),
               i=0,ne-1)
      905    continue

      910  continue
C     WRITE OUT REMAINING LINES

         if (lextra.gt.0) then
           line3 = nl-lextra+1
           do 915, iy = 0,lextra-1
              irec = line3+iy
              read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
              write (iuo,rec=irec) (bufi(i,0),i=0,ne-1)
      915     continue
         endif

         return
         end

C--------------------------------------------------------

         subroutine newaij (ir,iw,nbe,id,a,sigma,u,v,
           fc,dfc,ratio
        1,iform,thrshl,coeff,power,fmin,fmax)

         logical first
```

```
      dimension a(0:nbe-1,0:nbe-1)
      dimension sigma(0:nbe-1),id(0:nbe-1)
      dimension u(0:nbe-1,0:nbe-1),v(0:nbe-1,
     0:nbe-1)
      dimension fc(0:39),dfc(0:39),ratio(0:39)

       data first/.true./

       if(first) then
       write (iw,8888) iform,thrshl,power,fmin,
            fmax,coeff
 8888      format (' newaij: iform,t1,p,t2,c = ',
             i5,4f6.2)
       first=.false.
       endif

      do 100, j = 0,nbe-1
        do 100, i = 0,nbe-1
          a(i,j) = 0.
  100 continue

c     determine threshold formula

       if(iform.eq.6) then
       call iform6(ir,iw,nbe,id,a,sigma,u,v,fc,
          dfc,ratio
     1,iform,thrshl,coeff,power,fmin,fmax)
       endif

       return
       end

c-------------------------------------------------------
c     Boost formula 6
```

```
      subroutine iform6 (ir,iw,nbe,id,a,sigma,u,v,
     1        fc,dfc,ratio
     1,iform,shrshl,coeff,power,fmin,fmax)

      dimension a(0:nbe-1,0:nbe-1)
      dimension sigma(0:nbe-1),id(0:nbe-1)
      dimension u(0:nbe-1,0:nbe-1),v(0:nbe-1,
     1        0:nbe-1)
      dimension fc(0:39),dfc(0:39),ratio(0:39)

      do 120, l = 0,nbe-1

c     depending on IFORM choose threshold level

        ff = 1.

        if (sigma(l).ge.0.) then
          zz = (sigma(l)-fc(l))/dfc(l)

          if (zz.le.thrshl) then
            ff = fmin
          else if (zz.gt.thrshl) then
            arg = coeff*((zz-thrshl)**power)
            if (arg.le.0.000000001) then
               delf = delf*(1.+arg)
            else if (arg.gt.0.000000001.and.arg.
     1           le.10.) then
               delf = delf*(1.-exp(-arg))
            else if (arg.gt.10.) then
               delf = delf
            endif
c                end of arg ?

            ff = fmin + delf
          endif
```

```
                    enf of (zz...
                else if(sigma(1).eq.0.) then
                ff=1.

      5         else if (sigma(1).lt.0.) then
                write (iw,505) ix,iy,1,sigma(1)
          505   format (' ix,iy,1,sigma(1)',3i5,e15.5)
                ff = 1.
              endif
     10   c   end of (sigma(1)...

              do 110, j = 0,nbe-1
               do 110,i = 0,nbe-1
                 a(i,j) = a(i,j)+ff*sigma(1)*u(i,id(1))*
     15                  v(j,id(1))
          110   continue

          120 continue
               return
     20        end

          c-----------------------------------------------

              subroutine nfile(ir,iw,iun,nbe,ixsmpl,
     25                    iysmpl,fc,dfc,ratio)

              character*32        text,fname

              dimension fc(0:nbe-1),dfc(0:nbe-1),
     30              ratio(0:nbe-1)

              text='svd noise file for    0 degree'
              call ascnam(ir,iw,text,fname)
              call ascopn(iun,fname,'old',' ')
     35
```

```
      read(iun,*) nbe,ixsmpl,iysmpl

      write(iw,115) fname
  115    format(' noise file:',a32,/
     1 lx,'order',10x,' mean',10x,'sigma',10x,
              'ratio')

      do 802 l=0,nbe-1
      read(iun,*) iorder,fc(l),dfc(l),ratio(l)
      write(iw,116) iorder,fc(l),dfc(l),ratio(l)
  116    format(lx,i5,3el5.5)
  802    continue
  c           enddo          !loop l
      close(unit=iun)

      return
      end
```

APPENDIX F


```
c       svd_util.for
c       subroutines called by :
c                filter.for,  convol.for, ingn.for
c                svd_basic.for,  svd_move.for
c                svdnoi.for, and svd_move_3ori.for
c
c       OCT-26-87
c-----------------------------------------------------
c       subroutine svd(nm,m,n,a,w,matu,u,matv,v,
                ierr,rv1)
                                        compute svd
c       sort(n,s,id)                    sort svd
c       ifile(ir,iw,iui,lform,          open input picture
           lrec)                           file
c       ofile(ir,iw,iuo,lform,          open output picture
           lrec)                           file
c       wfile(ir,iw,iuw,modew,          get pre/post
           nbe,wt,sum)                     processing weights
c       picsiz(ir,iw,mode,nc,           asks picture size
           ne,nl)
c       recsiz(ir,iw,ne,lform,          asks record size
           lrec)
c       winsiz(ir,iw,ne,nl,ixl,         asks window size
           iyl,ixh,iyh)
c       boxsiz(ir,iw,ix0,iy0,           asks box size
           nx,ny)
c       xyorig(ir,iw,ix0,iy0)           asks xy origin
c       blksiz(ir,iw,nbe,nbl)           asks block size
c       smplxy(ir,iw,ixsmpl,            asks sampling steps
           iysmpl)
```

```
c       dirnam(ir,iw,dname)          asks directory name
c       picnam(ir,iw,nfiles,         asks file names
           mode,fname)
c       picopn(iu,fname,lrec,        opens a picture file
           status,com)
c       ascopn(iu,fname,status,      opens an ascii file
           com)
c       ascnam(ir,iw,text,           asks an ascii file
           fname)                       name
c       clrasc(n,text)               clears an ascii array
c       rdlin(iu,n,buf,com,          read a line
           irec)
c       wrlin(iu,n,buf,com,          write a line
           irec)
c       ptr0(n,lp)                   pointer
                                        initialization
c       ptr(n,lp)                    update a line pointer
c       clr(n,z)                     z(i)=0
c       movxs(n,ixs,buf,pic)         pic(i) gets sampled
                                        buf(i)
c       movxsi(n,ixs,pic,buf)        inverse of movxs
c       mulcy(n,c,y,z)               z(i)=z(i)+c*y(i)
c       dskdiv(iuil,iu2,lrec,
           buf,ne,nl,fdiv)
c                 read a line, div by const and write
                     back
c-----------------------------------------------------------
c
      subroutine svd(nm,m,n,a,w,matu,u,matv,v,ierr,
     1           rv1)
      integer i,j,k,l,m,n,ii,il,kk,kl,ll,ll,mn,nm,
     1           its,ierr
      real a(nm,n),w(n),u(nm,n),v(nm,n),rv1(n)
      real c,f,g,h,s,x,y,z,scale,anorm
      logical matu,matv
```

```
      c
      c  this subroutine is from the book "computer methods
      c  for mathematical computations" by g.e. forsythe,
      c  m.a. malcolm, and c.b. moler, 1977. prentice-hall,
      c  inc., englewood cliffs, new jersey 07632. pp. 229-
      c  235.
      c
      c  this subroutine determines the singular value
      c  decomposition
      c       t
      c   a=usv of a real m by n rectangular matrix.
             householder
      c  bidiagonalization and a variant of the qr
             algorithm are used.
      c
      c  on input:
      c   nm must be set to the row dimension of two-
             dimensional array
      c   parameters as declared in the calling program
             dimension statement.
      c   note that nm must be at least as large as the
             maximum of m and n.
      c
      c   m is the number of rows of a (and u).
      c   n is the number of columns of a (and u) and the
             order of v.
      c   a contains the rectangular array to be
             decomposed.
      c
      c   matu should be set to .true. if the u matrix in
      c      the decomposition is desired, and to .false.
      c      otherwise.
      c
      c   matv should be set to .true. if the v matrix in
             the decomposition is desired, and to .false.
```

```
      otherwise.
c  on output:
c   a is unaltered (unless overwritten by u or v).
c
c   w contains the n (non-negative) singular values
c      of a (the diagonal elements of s). they are
c      unordered. if an error exit is made, the
c      singular values should be correct for indices
c      ierr+1, ierr+2, ..., n.
c
c   u contains the matrix u (orthogonal column
c      vectors of the decomposition if matu has been
c      set to .true. otherwise, u is used as a
c      temporary array. u may coincide with a. if an
c      error exit is made, the columns of u
c      corresponding to indices of correct singular
c      values should be correct.
c
c   v contains the matrix v (orthogonal) of the
c      decomposition if matu has been set to .true.
c      otherwise, v is not referenced. v may also
c      coincide with a if u is not needed. if an
c      error exit is made, the columns of v
c      corresponding to indices of correct singular
c      values should be correct.
c
c   ierr is set to
c      zero     for normal return
c      k        if the k-th singular values has not
c                 been determined after 30 iterations.
c
c   rv1 is a temporary storage array.
c
      ierr=0
      do 100 j=1,n
```

```
      do 100 i=1,m
      u(i,j)=a(i,j)
100       continue
c   householder reduction to bidiagonal form
      g=0.0
      scale=0.0
      anorm=0.0
c
      do 300 i=1,n
      l=i+1
      rv1(i)=scale*g
      g=0.0
      s=0.0
      scale=0.0
      if(i.gt.m) goto 210
c
      do 120 k=i,m
120       scale=scale+abs(u(k,i))
c
      if(scale.eq.0.0) goto 210
c
      do 130 k=i,m
      u(k,i)=u(k,i)/scale
      s=s+u(k,i)**2
130       continue
c
      f=u(i,i)
      g=-sign(sqrt(s),f)
      h=f*g-2
      u(i,i)=f-g
      if(i.eq.n) goto 190
c
      do 150 j=1,n
      s=0.0
c
```

```
            do 140 k=i,m
                s=s+u(k,i)*u(k,j)
      c
            f=s/h
      c
            do 150 k=i,m
            u(k,j)=u(k,j)+f*u(k,i)
      150       continue
      c
      190       do 200 k=i,m
      200       u(k,i)=scale*u(k,i)
      c
      210       w(i)=scale*g
            g=0.0
            s=0.0
            scale=0.0
            if(i.gt.m.or.i.eq.n) goto 290
      c
            do 220 k=1,n
      220       scale=scale+abs(u(i,j))
      c
            if(scale.eq.0.0) goto 290
      c
            do 230 k=1,n
            u(i,k)=u(i,k)/scale
            s=s+u(i,k)**2
      230       continue
      c
            f=u(i,1)
            g=-sign(sqrt(s),f)
            h=f*g-s
            u(i,1)=f-g
      c
            do 240 k=1,n
      240       rv1(k)=u(i,k)/h
```

```
      c
            if(i.eq.m) goto 270
      c
            do 260 j=1,m
            s=0.0
      c
            do 250 k=1,n
      250       s=s+u(j,k)*u(i,k)
      c
            do 260 k=1,n
            u(j,k)=u(j,k)+s*rv1(k)
      260       continue
      c
      270       do 280 k=1,n
      280       u(i,k)=scale*u(i,k)
      c
      290       anorm=amax1(anorm,abs(w(i))+abs(rv1(i)))
      300       continue
      c ... accumulation of right-hand transformation .....
            if(.not.matv) goto 410
      c ...  for i=n step -1 until 1 do ....
            do 400 ii=1,n
            i=n+1-ii
            if(i.eq.n) goto 390
            if(g.eq.0.0) goto 360
      c
            do 320 j=1,n
      c ...  double division avoids possible underflow ....
      320      v(j,i)=(u(i,j)/u(i,1))/g
      c
            do 350 j=1,n
            s=0.0
      c
            do 340 k=1,n
      340       s=s+u(i,k)*v(k,j)
```

```
      c
            do 350 k=1,n
            v(k,j)=v(k,j)+s*v(k,i)
      350       continue
      c
      360       do 380 j=1,n
            v(i,j)=0.0
            v(j,i)=0.0
      380       continue
      c
      390       v(i,i)=1.0
            g=rv1(i)
            l=i
      400       continue
      c ... accumulation of left-hand transformations ...
      410       if(.not.matu) goto 510
      c ... for i=min(m,n) step -1 until 1 do ...
            mn=n
            if(m.lt.n) mn=m
      c
            do 500 ii=1,mn
            i=mn+1-ii
            l=i+1
            g=w(i)
            if(i.eq.n) goto 430
      c
            do 420 j=1,n
      420       u(i,j)=0.0
      c
      430       if(g.eq.0.0) goto 475
            if(i.eq.mn) goto 460
      c
            do 450 j=1,n
            s=0.0
      c
```

```
            do 440 k=1,m
      440       s=s+u(k,i)*u(k,j)
      c ...  double division avoids possible underflow
            f=(s/u(i,i))/g
      c
            do 450 k=i,m
            u(k,j)=u(k,j)+f*u(k,i)
      450       continue
      c
      460       do 470 j=i,m
      470       u(j,i)=u(j,i)/g
      c
            goto 490
      c
      475       do 480 j=i,m
      480       u(j,i)=0.0
      c
      490       u(i,i)=u(i,i)+1.0
      500       continue
      c
      c   diagonalization of the bidiagonal form ...
      c   for k=n step -1 until 1 do ...
      510       do 700 kk=1,n
            k1=n-kk
            k=k1+1
            its=0
      c   test for splitting
      c       for l=k step -1 until 1 do ...
      520       do 530 ll=1,k
            l1=k-l1
            l=l1+1
            if(abs(rv1(l))+anorm.eq.anorm) goto 565
      c   rv1(1) is always zero, so there is no exit
      c      through the bottom of the loop ...
            if(abs(w(l1))+anorm.eq.anorm) goto 540
```

```
      530         continue
      c   cancellation of rvl(l) if l greater than l ...
      540         c=0.0
                  s=1.0
      c
                  do 560 i=l,k
                  f=s*rvl(i)
                  rvl(i)=c*rvl(i)
                  if(abs(f)+anorm.eq.anorm) goto 565
                  g=w(i)
                  h=sqrt(f*f+g*g)
                  w(i)=h
                  c=g/h
                  s=-f/h
                  if(.not.matu) goto 560
      c
                  do 550 j=l,m
                  y=u(j,ll)
                  z=u(j,i)
                  u(j,ll)=y*c+z*s
                  u(j,i)=-y*s+z*c
      550         continue
      c
      560         continue
      c   test for convergence ..
      565         z=w(k)
                  if(l.eq.k) goto 650
      c   shift from bottom 2x2 minor ...
                  if(its.eq.30) goto 1000
                  its=its+l
                  x=w(l)
                  y=w(kl)
                  g=rvl(kl)
                  h=rvl(k)
                  f=((y-z)*(y+z)+(g-h)*(g+h))/(2.0*h*y)
```

```
                g=sqrt(f*f+1.0)
                f=((x-z)*(x+z)+h*(y/(f+sign(g,f))-h))/x
      c   next qr transformation ...
                c=1.0
                s=1.0
      c
                do 600 il=1,kl
                i=il+1
                g=rv1(i)
                y=w(i)
                h=s*g
                g=c*g
                z=sqrt(f*f+h*h)
                rv1(il)=z
                c=f/z
                s=h/z
                f=x*c+g*s
                g=-x*s+g*c
                h=y*s
                y=y*c
                if(.not.matv) goto 575
                do 570 j=1,n
                x=v(j,il)
                z=v(j,i)
                v(j,il)=x*c+z*s
                v(j,i)=-x*s+z*c
      570           continue
      c
      575           z=sqrt(f*f+h*h)
                w(il)=z
      c   rotation can be arbitrary if z is zero ...
                if(z.eq.0.0) goto 580
                c=f/z
                s=h/z
      580           f=c*g+s*y
```

```
            x=-s*g+c*y
            if(.not.matu) goto 600
      c
            do 590 j=1,m
            y=u(j,il)
            z=u(j,i)
            u(j,il)=y*c+z*s
            u(j,i)=-y*s+z*c
      590       continue
      c
      600       continue
      c
           rvl(l)=0.0
           rvl(k)=f
           w(k)=x
           goto 520
      c    convergence ...
      650       if(z.ge.0.0) goto 700
      c    w(k) is made non-negative ...
           w(k)=-z
           if(.not.matv) goto 700
      c
           do 690 j=1,n
      690       v(j,k)=-v(j,k)
      c
      700       continue
      c
          goto 1001
      c    set error .. no convergence to a singular value
      c                    after 30 iterations ...
      1000      ierr=k
      1001      return
           end

      c-----------------------------------------------------
```

```
      subroutine sort(n,s,id)
      dimension s(0:49),id(0:49)
c
c     arrary id contains index of array s after
        sorting permutation
c
      do 20 i=0,n-1
          id(i)=i
20     continue

      do 30 j=1,n-1
          v=s(j)
          idv=id(j)
        do 40 i=0,j-1
            if(v.lt.s(i)) goto 40
            do 50 k=i,j-1
            il=j+i-k
                i2=il-1
            s(il)=s(i2)
             id(il)=id(i2)
50        continue
         s(i)=v
         id(i)=idv
        go to 30
40     continue
30    continue
     return
     end

c-------------------------------------------------

      subroutine ifile(ir,iw,iui,lform,lrec)

      character*32          fnamei
```

```
      call picnam(ir,iw,1,'i',fnamei)
      call picopn(iui,fnamei,lrec,'old',' ')
c      !readonly

      return
      end

c-------------------------------------------------

      subroutine ofile(ir,iw,iuo,lform,lrec)

      character*32          fnameo

      call picnam(ir,iw,1,'o',fnameo)
      call picopn(iuo,fnameo,lrec,'new',' ')

      return
      end

c-------------------------------------------------

      subroutine wfile(ir,iw,iuw,modew,nbe,wt,sum)

      character*32 text,wname

      dimension wt(0:nbe-1)

      write(iw,402)
402       format(' weight option(-1:2)'
     1,/,' -1: pre weighting'
     1,/,'  0: no weighting'
     1,/,'  1: post weighting'
     1,/,'  2: pre and post weighting'
     1,/,' weight mode ?')
```

```
          read(ir,*) modew
    c408       format(i)

          if(modew.ne.0) then

          text='1-dim weight file'
          call ascnam(ir,iw,text,wname)
          call ascopn(iuw,wname,'old',' ')

          read(iuw,*) nbew,idum,idum,idum,gsigma,dummy
                if(nbew.ne.nbe) then
                write(iw,*) 'nbe.ne.nbew'
                stop
                endif
          do 801 i=0,nbe-1
          read(iuw,*) iorder,wt(i)
    c424     format(1x,i5,e15.5)
    801      continue
    c         enddo          !loop i

          sum=0.
          do 802 i=0,nbe-1
          sum=sum+wt(i)
    802      continue
    c         enddo          !loop i

          endif
    c         !modew ?

          return
          end

    c-------------------------------------------------

          subroutine picsiz(ir,iw,mode,nc,ne,nl)
```

```
      character*1 mode

      if(mode.eq.'i'.or.mode.eq.'I') then
 5  1   write(iw,2)
    2     format(' input image size: colors,
     *          elements,lines ?')
      else if(mode.eq.'o'.or.mode.eq.'0') then
      write(iw,4)
10  4     format(' output image size: colors,
     *          elements,lines ?')
      endif

      read(ir,*) nc,ne,nl
15

      write(iw,20) nc,ne,nl
   20   format(' picsiz: nc,ne,nl = ',3i7)

      return
20    end

C-----------------------------------------------
      subroutine recsiz(ir,iw,ne,lform,lrec)

25  1 write(iw,10)
   10  format(' format 69 or 81 or 99(sun) or 77
     *        (cray) (i) ?')
      read(ir,*) lform

30    if(lform.eq.69) then
      lrec=ne
      else if(lform.eq.77) then
      lrec=ne*8
      else if(lform.eq.99) then
35    lrec=ne*4
```

```
      c       !since sun recordlength is in bytes
              else if(lform.eq.81) then
              lrec=((ne*4-1)/512+1)*512/4
      c       !(ne*4) bytes
              endif
              write(iw,20) lform,lrec
      20        format(' recsiz: lform = ',i5,' lrec =
                       ',i5)

              return
              end

      c-----------------------------------------------

              subroutine winsiz(ir,iw,ne,nl,ixl,ixh,iyl,iyh)

        10      write(iw,12)
        12       format(' window size: ixl,ixh,iyl,iyh ?')
              read(ir,*) ixl,ixh,iyl,iyh

              if(ixl.eq.0.and.ixh.eq.0) then
              ixl=0
              ixh=ne-1
              endif
      c       !ixl,ixh

              if(iyl.eq.0.and.iyh.eq.0) then
              iyl=0
              iyh=nl-1
              endif
      c       !iyl,iyh

              write(iw,20) ixl,ixh,iyl,iyh
      20       format(' window: ixl,ixh,iyl,iyh = ',4i5)
```

```
      return
      end

C-----------------------------------------------
      subroutine boxsiz(ir,iw,ix0,iy0,nx,ny)

      write(iw,10)
10      format(' ix0,iy0,nx,ny ?')
      read(ir,*) ix0,iy0,nx,ny

      write(iw,20) ix0,iy0,nx,ny
20      format(' boxsiz: ix0,iy0,nx,ny = ',4i5)

      return
      end

C-----------------------------------------------

      subroutine xyorig(ir,iw,ix0,iy0)

      write(iw,10)
10      format(' ix0,iy0 ?')
      read(ir,*) ix0,iy0

      write(iw,20) ix0,iy0
20      format(' xyorig: ix0,iy0 = ',2i5)

      return
      end

C-----------------------------------------------
      subroutine blksiz(ir,iw,nbe,nbl)

      write(iw,10)
10      format(' block size nbe,nbl ?')
```

```
      read(ir,*) nbe,nbl

      write(iw,20) nbe,nbl
20      format(' blksiz: nbe,nbl = ',2i5)

      return
      end

c-----------------------------------------------

      subroutine smplxy(ir,iw,ixsmpl,iysmpl)

      write(iw,10)
10      format(' sampling ixsmpl,iysmpl ?')
      read(ir,*) ixsmpl,iysmpl

      write(iw,20) ixsmpl,iysmpl
20      format(' smplxy: ixsmpl,iysmpl = ',2i5)

      return
      end

c-----------------------------------------------

      subroutine picnam(ir,iw,nfiles,mode,fname)

      character*1 mode
      character*32 fname(0:nfiles-1)

      do 1 ifile=0,nfiles-1

      if(mode.eq.'i'.or.mode.eq.'I') then
      write(iw,22) ifile
22      format(1x,i3,'th input picture file
     1          (a32) ?')
```

```
      else if (mode.eq.'o'.or.mode.eq.'O') then
      write(iw,24) ifile
   24   format(1x,i3,'th output picture file
                (a32) ?')
      endif
c     !mode?

      read(ir,25) fname(ifile)
   25   format(a32)
    1   continue

      return
      end

c-------------------------------------------------

      subroutine picopn(iu,fname,lrec,status,com)

      character*1 com
      character*3 status
      character*32 fname
      data iw/6/

      if(com.eq.'s'.or.com.eq.'S') then
      open(unit=iu,file=fname,access='sequential',
                recl=lrec)
      else
      open(unit=iu,file=fname,access='direct',
                recl=lrec)
      endif

      write(iw,30) fname
   30   format(' picopn: file = ',a32)

      return
```

```
      end

C-----------------------------------------------

      subroutine ascopn(iu,fname,status,com)

      character*1 com
      character*3 status
      character*32 fname
      data iw/6/

      open(unit-iu,file=fname)

      write(iw,30) fname
30      format(' ascopn: file = ',a32)

      return
      end

C-----------------------------------------------

      subroutine ascnam(ir,iw,text,fname)

      character*32 text,fname

      write(iw,10) text
10      format(1x,a32,' name (a32) ?')
      read(ir,12) fname
12      format(a32)

      return
      end

C-----------------------------------------------
```

```
      subroutine clrasc(n,text)

      character*1 text(0:n-1)

      do 1 i=0,n-1
      text(i)=' '
    1  continue

      return
      end

c-----------------------------------------------
c     read and write routines
c-----------------------------------------------

      subroutine rdlin(iu,n,buf,com,irec)

      character*1 com
      dimension buf(0:0)

      if(com.eq.'s'.or .com.eq.'S') then
      read(iu) (buf(i),i=0,n-1)
      else
      read(iu),rec=irec) (buf(i),i=0,n-1)
      endif

      return
      end

c-----------------------------------------------

      subroutine wrlin(iu,n,buf,com,irec)

      character*1 com
      dimension buf(0:0)
```

```
            if(com.eq.'s'.or .com.eq.'S') then
            write(iu) (buf(i),i=0,n-1)
            else
      5     write(iu,rec=irec) (buf(i),i=0,n-1)
            endif

            return
            end
     10
        c-------------------------------------------------

            subroutine ptr0(n,lp)

     15     dimension lp(0:0)

            do 1 i=0,n-1
            lp(i)=i
        1    continue
     20 c    !loop i

           return
           end

     25 c-------------------------------------------------

           subroutine ptr(n,lp)

        c    rotate the pointer by one
     30 c    lp(0) will have the oldest data
        c    lp(n-1) will have the newest data
        c    first  lp(0)=0, lp(1)=1,lp(2)=2.lp(3)=3,....
        c    then   lp(0)=1,lp(1)=2,lp(2)=3,lp(3)=4,....

     35    dimension lp(0:0)
```

```
            ll=lp(0)
      c      !save

 5          do 1 i=0,n-2
            lp(i)=lp(i+1)
      1      continue
      c      !enddo        !loop i

10          lp(n-1)=ll

            return
            end

15    c-----------------------------------------------
      c      arithmatic operation
      c-----------------------------------------------

            subroutine addc(n,c,z)
20
            dimension z(0:n-1)

            do 1 i=0,n-1
            z(i)=z(i)+c
25    1      continue
      c      !enddo

            return
            end
30
      c-----------------------------------------------

            subroutine clr(n,z)

35          dimension z(0:0)
```

```
            do 1 i=0,n-1
            z(i)=0.
             continue
 5
            return
            end
      c-----------------------------------------------

10          subroutine movxs(n,ixs,buf,pic)

            dimension buf(0:0),pic(0:0)

            if(ixs.eq.1) then
15                 do 1 i=0,n-1
                   pic(i)=buf(i)
     1              continue
            else
     c              !sample buf and put into pic
20                 do 2 i=0,n-1
                   pic(i)=buf(i*ixs)
     2              continue
            endif

25          return
            end

      c-----------------------------------------------

30          subroutine movxsi(n,ixs,pic,buf)

            dimension pic(0:0),buf(0:0)

            if(ixs.eq.1) then
35                 do 1 i=0,n-1
```

```
                buf(i)=pic(i)
     1           continue
                else
     c                   !put pic into sampled buf
                do 2 i=0,n-1
                buf(i*ixs)=pic(i)
     2           continue
                endif

                return
                end

     c-------------------------------------------------

                subroutine mulcy(n,c,y,z)

                dimension y(0:0),z(0:0)

                do 1 i=0,n-1
                z(i)=z(i)+c*y(i)
     1           continue
     c           !loop z

                return
                end

     c-------------------------------------------------

                subroutine clrx(n,data)

                dimension data(0:0)

                do 1 i=0,n-1
                data(i)=0.
     1           continue
```

```
c        loop i

         return
         end

c-----------------------------------------------------

         subroutine dskdiv(iul,iu2,lrec,buf,ne,nl,
                  fdiv)

c        read a direct access file,
c        divide each pixel by fdiv and
c        write back

         dimension buf(0:0)

         do 1 irec=1,nl
         read(iul,rec=irec) (buf(i),i=0,ne-1)
                do 2 i=0,ne-1
                buf(i)=buf(i)/fdiv
2                continue
c        loop i
         write(iu2,rec=irec)
(buf(i),i=0,ne-1)231       continue
c        loop irec

         return
         end
```

APPENDIX G


```
C     SHARPENING AND NOISE SUPPRESSION BY SINGULAR
      VALUE DECOMPOSITION

C     SVD_MOVE.FOR -- SVD WITH MOVING AVERAGE

C         link with svd_util.f

C     DEC-20-88

C     maximum svd block size: 40x40

      dimension  bufi(0:1999,0:39)
      dimension  bufo(0:1999,0:39)
      dimension  a(0:39,0:39),u(0:39,0:39),
          v(0:39,0:39)
      dimension  wt(0:39)

      dimension fc(0:39,dfc(0:39),ratio(0:39)

      data ir,iw/5,6/

      data iui,iuo,iun/51,52,53/
      data iuw/61/
      data a,u,v/1600*0.,1600*0.,1600*0./
      data wt/40*0./
      data fc,dfc,ratio/40*0.,40*0.,40*0./

C     NBE: # of elements per block (BLOCK SIZE)
C     NE: number of pixels per linbe (e.g. 500
          pixels)
C     NL: number of linbes of the image
```

```
      c       ixsmpl,iysmpl : sampling in x and y directions

      c       INPUT

      c       define image size : nc,ne,nl
              call picsiz (ir,iw,'I',nc,ne,nl)

      c       define image record size
              call recsiz (ir,iw,ne,lform,lrec)

      c       open input image file
              call ifile (ir,iw,iui,lform,lrec)

      c       read noise data file
              call nfile (ir,iw,iun,nbe,ixsmpl,iysmpl,fc,
                  dfc,ratio)

      c       open output image file
              call ofile (ir,iw,iuo,lform,lrec)

      c       get pre/post processing weights
              call wfile (ir,iw,iuw,modew,nbe,wt,sum)

              write (iw,122)
      122     format (' Starting IX0,IY0 ?')
              read (ir,*) ix0,iy0

      c       block orientation mode = 0 (0 or 90 degree)
              modeb=0

              write (iw,140)
      140     format(' idx,idy: No. of pixels to be moved '
             1,'in X and Y directions'/)
              read (ir,*)idx,idy
```

```
      write (iw,151)
  151 format (' Boost formula'
     3,/,' 6: THRESHOLD1 ,EXP(-A*X**4) AND FMIN,
        FMAX')

      write (iw,152)
  152 format (' Boost FORMULA(I) ?')
      read (ir,*) iform

      write (iw,162)
  162 format (" THRSH1(R),POWER(R),FMIN,FMAX,
         COEFF(FOR 6:) ?')
      read (ir,*) thrsh1,power,fmin,fmax,coeff

      msize = ixsmpl*(nbe-1)+1
      nbsize = ixsmpl*nbe
      nbsiz2 = ixsmpl*nbe/2
      nxmove = nbsize/idx
      nymove = nbsize/idy

      write (iw,202)nbe,ix0,iy0,ixsmpl,iysmpl
     1          ,msize,nbsize,idx,idy,nxmove,nymove

      if (mode.ne.0) then
        write (iw,204) modew,sum
      endif

  202 format (' MAIN: NBE,IXO,IYO = ',T30,3I8
     1,/,' MAIN: IXSMPL,IYSMPL = ',T30,2I8
     2,/,' MAIN: SUPPORT SIZE = 'T30,I8
     3,/,' MAIN: NBE*IXSMPL = ',T30,I8
     4,/,' MAIN: IDX,IDY = ',T30,2I8
     5,/,' MAIN: NX ,NY = ',T30,2I8)
  204 format (' MODEW, SUM OF WEIGHTS = ',I5,E15.5)
```

```
            do 305, mj = 0,nymove-1
              jy0 = iy0+mj*idy
              do 305, mi = 0,nxmove-1
                jx0 = ix0+mi*idx
     5          mseq = mj*nxmove+mi
                call hui (nsvd,ir,iw,iui,iuo,nc,ne,nl,nbe,
                          ixsmpl,iysmpl
          1              ,bufi,bufo,a,u,v,fc,dfc,ratio
          2              ,iform,thrshl,coeff,power,fmin,
    10                    fmax
          3              ,jx0,jy0,idx,idy,mseq,modew,wt,
                          lrec)

                if (mseq.eq.mseq/10*10) then
    15            write (iw,304) mi,mj
         304      format (1X,' MAIN: BLOCK X,Y = ',2I5,'
                     DONE')
                endif
         305    continue
    20          write(iw,333)nsvd
         333    format(1x,' *** total number of svd called :
                   ',i10)
          C     ALL THE SUM IS ACCUMULATED IN OUTPUT FILE
                READ IT AND DIVIDE BY NXMOVE*NYMOVE
    25
                denom = float(nxmove*nymove)
                if (modew.eq.1.or.modew.eq.2) then
                   denom = (sum*sum*denom)/(nbe*nbe)
                endif
    30
                call dskdiv (iuo,iuo,lrec,bufo,ne,nl,denom)

                close (iui)
                close (iuo)
    35
```

```
      end

c-----------------------------------------------

      subroutine hui(nsvd,ir,iw,iui,iuo,nc,ne,nl,
     1     nbe,ixsmpl,iysmpl
     1     ,bufi,bufo,a,u,v,fc,dfc,ratio
     2     ,iform,thrshl,coeff,power,fmin,fmax
     3     ,jx0,jy0,idx,idy,mseq,modew,wt,lrec)

c     GIVEN JXO,JYO(STARTING POINT), IT WILL MAKE
c       IXSMPL*IYSMPL
C     MOVES OF BLOCK TRANSFORM

C     THIS SUBROUTINE DOES ALL THE ACTUAL
C        PROCESSING
C     MAIN PROGRAM JUST SETS UP ARRAY SIZES FOR A
C        GIVEN PICTURE.

      dimension  bufi(0:ne-1,0:nbe-1)
      dimension  bufo(0:ne-1,0:nbe-1)
      dimension  a(0:nbe-1,0:nbe-1)
      dimension  u(0:nbe-1,0:nbe-1),
     1              v(0:nbe-1,0:nbe-1)
      dimension  work(100)
      dimension  fc(0:39),dfc(0:39),ratio(0:39)
      dimension  id(0:39),sigma(0:39)
      dimension  wt(0:nbe-1)

      n        = nbe
      m        = nbe
      nm       = nbe
      nbrxs    = nbe*ixsmpl
```

```
      nxtry    = (ne-jx0-nbe)/nbrxs-1
      nytry    = (nl-jy0-nbe)/nbrxs
      if  (((nytry-1)*nbrxs+nbe).gt.nl) then
        nytry = nytry-1
      endif
      lextra = nl-nytry*nbrxs-jy0

      if (mseq.eq.0) then
        write (iw,802) nbe,ixsmpl,iysmpl,
     1       iform,thrshl,power,fmin,fmax,coeff
  802   format (' HUI:nbe,ixsmpl,iysmpl=',3i5,/
     1     ,' boost formula, thrshl,power,fmin,fmax,
              coeff = '
     2     ,/,1x,I5,5E15.5)

      endif

c     skip jy0 lines
      if (jy).ge.1)then
          do 840, iy = 0,jy0-1
          irec = iy+1
          read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
          write (iuo,rec=irec) (bufi(i,0),i=0,ne-1)
  840     continue
      endif

c     processing the input image block by block

      do 910, iy = 0,nytry-1
        line1 = jy0+1+iy*nbrxs

        do 910, iys = 0,iysmpl-1
          line2 = line1+iys

c     read in nbe lines from the input image into
```

```
      bufi

       do 850, j = 0,nbe-1
        linei = line2+j*iysmpl
        read (iui,rec=linei) (bufi(i,j),i=0,ne-1)

c     if it is a first path :
c           initialize the output buffer -- bufo
c      otherwise : read in output buffer -- bufo

       if (mseq.eq.0) then
         do 845, jj = 0,nbe-1
         do 845,ii = 0,ne-1
           bufo(ii,jj) = 0.
845      continue
       else if (mseq.ne.0) then
       read (iuo,rec=linei) (bufo(i,j),i=0,ne-1)
       endif
850    continue

c     set up array a(i,j)

      do 900, ix = 0,nxtry-1
        ixoff1 = jx0+nbrxs*ix

        do 900, ixs = 0,ixsmpl-1
          ixoff2 = ixoff1+ixs+(nbe/2)*ixsmpl
            do 860, j = 0,nbe-1
            do 860, i = 0,nbe-1
            ii = ixoff2+i*ixsmpl
            a(i,j) = bufi(ii,j)
860         continue

      call svd (nm,m,n,a,sigma,.true.,u,.true.,v,
        ierr,work)
```

```
              nsvd=nsvd+1

              if (ierr.ne.0) then
                write (iw,20) ix,iy,ierr
   5  20          format (' TROUBLE. IX,IY,IERR= ',3I6)
                do 865, l = 0,nbe-1
                  write (iw,22) l,sigma(l)
       22         format (1x,i3,'th singular value =
                         ',E15.5)
  10   865       continue
                do 866 i=0,ierr-1
                sigma(i)=0.
       866      continue
              endif
  15
       c      sort sigma(==singular values) in descending
                order

              call sort (nbe,sigma,id)
  20   c
       c      SIGMA(I,L(ID)): Ith SINGULAR VALUE

       C      COMPUTE NEW A(I,J) ACCORDING TO CORING FORMULA
       C          (IFORM) FROM
  25   C      SIGMA, U, AND V.

              call newaij (ir,iw,nbe,id,a,sigma,u,v,
                 fc,dfc,ratio
            1    ,iform,thrshl,coeff,power,fmin,fmax)
  30
              if (modew.eq.-1) then
                do 885, j = 0,nbe-1
                do 885, i = 0,nbe-1
                  a(i,j) = a(i,j)/wt(i)/wt(j)
  35   885       continue
```

```
                else if (modew.eq.1) then
                  do 890, j = 0,nbe-1
                  do 890, i = 0,nbe-1
                    a(i,j) = a(i,j)*wt(i)*wt(j)
 5  890             continue
                endif

     C       UPDATE OUTPUT BUFFER : BUFO

10
                do 895, j = 0,nbe-1
                jj = j
                do 895, i = 0,nbe-1
                  ii = ixoff2+1*ixsmpl
                  bufo(ii,jj) = bufo(ii,jj)+a(i,j)
15  895           continue

     900        continue

     C       WRITE LINES OUT TO DISK (AFTER NN LINES, MM
20           BLOCKS ARE PROCESSED)

                do 905, j = 0,nbe-1
                  lineo = line2+j*iysmpl
                  write (iuo,rec+lineo) (bufo(i,j),i=0,ne-1)
25  905         continue

     910        continue

     C       WRITE OUT REMAINING LINES
30
                if (lextra.gt.0) then
                  line3 = nl=lextra+1
                  do 915, iy = 0,lextr-1
                    irec = line3+iy
35                  read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
```

```
            write (iuo,rec=irec) (bufi(i,0),i=0,ne-1)
      915   continue
            endif

            return
            end

      c-----------------------------------------------------

            subroutine newaij (ir,iw,nbe,id,a,sigma,u,v,
                 fc,dfc,ratio
           1,iform,thrshl,coeff,power,fmin,fmax)

            logical first
            dimension a(0:nbe-1,0:nbe-1)
            dimension sigma(0:nbe-1,id(0:nbe-1)
            dimension u(0:nbe-1,0:nbe-1),v(0:nbe-1,
                   0:nbe-1)
            dimension fc(0:39),dfc(0:39),ratio(0:39)

            data first/.true./

            if(first) then
            write (iw,8888) iform,thrshl,power,fmin,
                   fmax,coeff
      8888     format (' newaij: iform,t1,p,t2,c =
                     ',i5,4f6.2)
            first=.false.
            endif

           do 100, j = 0,nbe-1
            do 100, i = 0,nbe-1
              a(i,j) = 0.
      100   continue
```

```
c     determine threshold formula

      if(iform.eq.6) then
      call iform6(ir,iw,nbe,id,a,sigma,u,v,fc,
     5          dfc,ratio
     l,iform,thrshl,coeff,power,fmin,fmax)
      endif

      return
     10 end

c-----------------------------------------------
c     Boost formula 6

     15 subroutine iform6 (ir,iw,nbe,id,a,sigma,u,v,
          fc,dfc,ratio
     l,iform,thrshl,coeff,power,fmin,fmax)

      dimension a(0:nbe-1,0:nbe-1)
     20 dimension sigma(0:nbe-1),id(0:nbe-1)
      dimension u(0:nbe-1,0:nbe-1),v(0:nbe-1,
           0:nbe-1)
      dimension fc(0:39),dfc(0:39),ratio(0:39)

     25 do 120, l = 0,nbe-1

c     depending on IFORM choose threshold level

      ff - 1.
     30
      if (sigma(l).ge.0.) then
        zz = (sigma(l)-fc(l))/dfc(l)

        if (zz.le.thrshl) then
     35   ff = fmin
```

```
                else if (zz.gt.thrshl) then
                  arg = coeff*((zz-thrshl)**power)
                  if (arg.le.0.000000001) then
                    delf = delf*(1.+arg)
                  else if (arg.gt.0.000000001.and.arg.
                          le.10.) then
                    delf = delf*(1.-exp(-arg))
                  else if (arg.gt.10.) then
                    delf = delf
                  endif
              c       end of arg ?

                  ff = fmin + delf
                endif
              c       end of (zz...

              else if(sigma(l)eq.0.) then
              ff=1.

              else if (sigma(l).lt.0.) then
                write (iw,505) ix,iy,l,sigma(l)
          505   format (' ix,iy,l,sigma(l)',3i5,e15.5)
                ff = 1.
              endif
              end of (sigma(l)...

               do 110, j = 0,nbe-1
                do 110, i = 0,nbe-1
                  a(i,j) = a(i,j)+ff*sigma(l)*u(i,id(l))*
                           v(j,id(l))
          110  continue

          120 continue
               return
              end
```

```
c-----------------------------------------------------

      subroutine nfile(ir,iw,iun,nbe,ixsmpl,
     5     iysmpl,fc,dfc,ratio)

      character*32          text,fname

      dimension fc(0:nbe-1),dfc(0:nbe-1),
     10     ratio(0:nbe-1)

      text='svd noise file for      0 degree'

      call ascnam(ir,iw,text,fname)
     15   call ascopn(iun,fname,'old',' ')

      read(iun,*) nbe,ixsmpl,iysmpl

      write(iw,115) fname
     20 115    format(' noise file:',a32,/
     1 5x,'order',5x,' mean',5x,'sigma',5x,'ratio')

      do 802 l=0,nbe-1
      read(iun,*) iorder,fc(l),dfc(l),ratio(l)
     25   write(iw,116) iorder,fc(l),dfc(l),ratio(l)
     116    format(1x,i5,3e15.5)
     802    continue
     c              end of loop l
      close(unit=iun)
     30

      return
      end


     35
```

APPENDIX H


```
c       sml_filter.for
c       generate s,m and l low-pass filters
c       output filter file names: s.msk -- 3x3
c                                 m.msk -- 5x5
c                                 l.msk -- 7x7

c       OCT-26-87

        character*32 fname(0:2)
        dimension s(0:8),ixsmpl(0:2),iysmpl(0:2)

        data ir,iw/5,6/
        data iu,iu2/99,98/
        data s/1.,2.,1.,2.,4.,2.,1.,2.,1./
        data fname/'s.msk','m.msk','l.msk'/
        data ixsmpl/1,2,4/
        data iysmpl/1,2,4/

        write(iw,10)
10      format(/,' : generates s.msk, m.msk and
               l.msk '
     1 ,'low pass filter files',/)

c       input

        sigmax=0.
        sigmay=0.
        nbe=3
        nbl=3

c       output
```

```
      do 90 l=0,2

         open (unit=iu,file=fname(l))

         write(iu,102) nbe,nbl,ixsmpl(1),iysmpl(1),
              sigmax,sigmay
102      format(1x,4i5,2e15.5)
         do 50 i=0,nbe*nbl-1
         write(iu,104) i,s(i)
104      format(1x,i5,e15.5)
50       continue
         close(iu)
90    continue

      end
```

APPENDIX I


```
C       SHARPENING AND NOISE SUPPRESSION BY SINGULAR
        VALUE DECOMPOSITION

C       SVD_MOVE_3ORI.F -- SVD WITH MOVING AVERAGE
        and 3 ORIENTATIONS

C          link with svd_util.f

C       DEC-20-88

C       maximum svd block size : 40x40

C       WITH THREE MODES:0--STRAIGHT
C                        1-45 DEGREE SLANT
C                        2-135 DEGREE SLANT
C       MOVING BLOCK AVERAGE
C       WITH SAMPLING IXSMPL,IYSMPL
C       IXO,IYO,AND SCALE FACTOR FOR NOISE
C       MAXIMUM BLOCK SIZE 40x40

        dimension  bufi(0:1999,0:39)
        dimension  bufo(0:1999,0:39)
        dimension  a(0:39,0:39),u(0:39,0:39),
                     v(0:39,0:39)
        dimension  wt(0:39)

        dimension  iun(0:2)
        dimension  fc(0:39,0:2),dfc(0:39,0:2),
                     ratio(0:39,0:2)

        data ir,iw/5,6/
```

```
      data iui,iuo,iun/51,52,53,54,55/
      data iuw/61/
      data a,u,v/1600*0.,1600*0.,1600*0./
      data wt/40*0./
      data fc,dfc,ratio/120*0.,120*0.,120*0./

C     NBE: # of elements per block  (BLOCK SIZE)
C     NE: number of pixels per linbe (e.g. 400
            pixels, or 1136 pixels)
C     NL: number of linbes of the image

c     INPUT

c     define image size : nc,ne,nl
      call picsiz (ir,iw,'I',nc,ne,nl)

c     define image record size
      call recsiz (ir,iw,ne,lform,lrec)

c     open input image file
      call ifile (ir,iw,iui,lform,lrec)

c     read noise data files
      call nfile (ir,iw,iun,nbe,ixsmpl,iysmpl,fc,
           dfc,ratio)

c     open output image file
      call ofile (ir,iw,iuo,lform,lrec)

c     get pre/post processing weights
      call wfile (ir,iw,iuw,modew,nbe,wt,sum)

      write (iw,122)
122   format (' Starting IX0,IY0 ?')
```

```
      read (ir,*) ix0,iy0

      write (iw,140)
  140 format ('NBR: No. of pixels to be replaced in
     5       the block'
     1/' IDX,IDY: No. of pixels to be moved in X
              and Y directions'/)

      write (iw,142)
  142 format (' NBR,IDX,IDY ?')
      read (ir,*) nbr,idx,idy

    c get block orientation mode
      write (iw,171)
  171 format (' Block selection mode:'
     1,/,' 0:      0 degree'
     1,/,' 1:     45 degree'
     1,/,' 2:    135 degree'
     1,/,' 3:   best of the above three'
     1,/,' MODEB ?')
      read (ir,*) modeb

      write (iw,151)
  151 format (' Boost formula'
     3,/,' 6: THRESHOLD1 , EXP(-A*X**4) AND
              FMIN,FMAX')

      write (iw,152)
  152 format (' Boost FORMULA(I) ?')
      read (ir,*) iform

      write (iw,162)
  162 format ('THRSH1(R),POWER(R),FMIN,FMAX,
             COEFF(FOR 6:) ?')
      read (ir,*) thrshl,power,fmin,fmax,coeff
```

```
      msize = ixsmpl*(nbe-1)+1
      nbsize = ixsmpl*nbe
      nbsiz2 = ixsmpl*nbe/2
      nxmove = nbsize/idx
      nymove = nbsize/idy

      write (iw,202) nbr,ix0,iy0,ixsmpl,iysmpl
     1               ,msize,nbsize,idx,idy,nxmove,
                     nymove

      if (modew.ne.0) then
        write (iw,204) modew,sum
      endif

  204 format (' MAIN: NBR,IX0,IY0, = ',%30,3I8
     1,/,' MAIN: IXSMPL,IYSMPL = ',T30,2I8
     1,/,' MAIN: SUPPORT SIZE = ',T30,I8
     1,/,' MAIN: NBE*IXSMPL = T30,I8
     1,/,' MAIN: IDX,IDY = ',T30,2I8)
     2,/,' MAIN: NX ,NY  = 'T30,2I8)
  204 format (' MODEW, SUM OF WEIGHTS = ',I5,E15.5)

      do 305, mj = 0,nymove-1
        jy0 = iy0+mj*idy
        do 305, mi = 0,nxmove-1
          jx0 = ix0+mi*idx
          mseq = mj*nxmove+mi
          call hui (nsvd,ir,iw,iui,iuo,nc,ne,nl,
                          nbe,ixsmpl,iysmpl
     1             ,bufi,bufo,lp,a,u,v,fc,dfc,
                          ratio
     2             ,iform,thrshl,coeff,power,fmin,
                          fmax
     3             ,jx0,jy0,idx,idy,mseq,nbr,modew,
```

```
                                wt,lrec,modeb)

                    if (mseq.eq.mseq/10*10) then
                      write (iw,304) mi,mj
  5   304               format (1X' MAIN: BLOCK X,Y = '2I5,'
                                DONE')
                    endif
        305       continue

 10             write(iw,333)nsvd
        333     format(1x," *** total number of svd called :
                     ',i10)

        C       ALL THE SUM IS ACCUMULATED IN OUTPUT FILE
 15     C       READ IT AND DIVIDE BY NXMOVE*NYMOVE

                denom = float(nxmove*nymove)
                if (modew.eq.1.or.modew.eq.2) then
                  denom = (sum*sum*denom)/(nbe*nbe)
 20             endif

                call dskdiv (iuo,iuo,lrec,bufo,ne,nl,denom)

                close (iui)
 25             close (iuo)
                end

        c-----------------------------------------------

 30             subroutine hui(nsvd,ir,iw,iui,iuo,nc,ne,nl,
                                nbe,ixsmpl,iysmpl
               1               ,bufi,bufo,lp,a,u,v,fc,dfc,
                                ratio
               2               ,iform,thrshl,coeff,power,
 35                             fmin,fmax
```

```
     3          ,jx0,jy0,idx,idy,mseq,nbr,
                       modew,wt,lrec,modeb)

     C     GIVEN JX0,JY0(STARTING POINT), IT WILL MAKE
     5        IXSMPL*IYSMPL
     C     MOVES OF BLOCK TRANSFORM

     C     THIS SUBROUTINE DOES ALL THE ACTUAL
              PROCESSING.
    10 C     MAIN PROGRAM JUST SETS UP ARRAY SIZES FOR A
              GIVEN PICTURE.

           dimension  bufi(0:ne-1,0:nbe-1)
           dimension  bufo(0:ne-1,0:nbe-1)
    15     dimension  a(0:nbe-1,0:nbe-1)
           dimension  u(0:nbe-1,0:nbe-1),v(0:nbe-1,
                         0:nbe-1)
           dimension  temps(0:39,0:2),tempu(0:39,0:39,
                         0:2)
    20     dimension  tempv(0:39,0:39,0:2),idtemp(0:39,
                         0:2)
           dimension  work(100)
           dimension  fc(0:39,0:2),dfc(0:39,0:2),
                         ratio(0:39,0:2)
    25     dimension  id(0:39,sigma(0:39)
           dimension  wt(0:nbe-1)

           n      = nbe
           m      = nbe
    30     nm     = nbe
           nbr2   = (nbe-nbr)/2
           nbr3   = nbr2+nbr
           nbrxs  = nbr*ixsmpl

    35     nxtry  = (ne-jx0-nbe)/nbrxs-1
```

```
      nytry  = (nl-jy0-nbe)/nbrxs
      if (((nytry-1)*nbrxs+nbe).gt.nl) then
        nytry = nytry-1
      endif
      lextra = nl-nytry*nbrxs-jy0+nbr2

      if (mseq.eq.0) then
        write (iw,802) modeb,nbe,nbr,ixsmpl,iysmpl,
     1         iform,thrshl,power,fmin,fmax,coeff
  802   format ('HUI: modeb,nbe,nbr,ixsmpl,iysmpl=
                ',5i5,/
     1         ,'boost formula,thrshl,power,fmin,
                fmax,coeff = '
     2 ,/,1x,I5,5E15.5)
        write (iw,804) lrec,ir,iw,iui,iuo
  804   format (' hui: lrec,ir,iw,iui,iuo = ',5i5)

        endif

c     skip jy0 lines

      if ((jy0+nbr2).ge.1)then
        do 840, iy = 0,jy0+nbr2-1
        irec = iy+1
        read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
        write (iuo,rec=irec) (bufi(i,0),i=0,ne-1)
  840   continue
      endif

c     processing the input image block by block

      do 910 iy = 0,nytry-1
        linel = jy0+1+iy*nbrxs

        do 910, iys = 0,iysmpl-1
```

```
            line2 = line1+iys

      c     read in nbe lines from the input image into
               bufi

            do 850, j = 0,nbe-1
              linei = line2+j*iysmpl
              read (iui,rec=linei) (bufi(i,j),i=0,ne-1)

      c     if it is a first path :
      c           initialize the output buffer -- bufo
      c        otherwise: read in output buffer    -- bufo

              if (mseq.eq.0) then
                do 845, jj = 0,nbe-1
                do 845, ii = 0,ne-1
                  bufo(ii,jj) = 0.
  845             continue
              else if (mseq.ne.0) then
              read (iuo,rec=linei) (bufo(i,j),i=0,
                     ne-1)
              endif
  850       continue

      c     set up array a(i,j)

            do 900, ix = 0,nxtry-1
              ixoff1 = jx0+nbrxs*ix

              do 900, ixs = 0,ixsmpl-1
                ixoff2 = ixoff1+ixs

                if (modeb.eq.3) then
                  model1 = 0
                  model2 = 2
```

```
      else
        modell = modeb
        model2 = modeb
      endif

      do 875, mode = modell,model2

C     COMPUTE SVD FOR 3 MODES:
C      0 : STRAIGHT BLOCK
C      1 : 45 DEG SLANT
C      2 : 135 DEG SLANT

       if (mode.eq.0) ixoff3 = ixoff2+
            (nbe/2)*ixsmpl
       if (mode.eq.1) ixoff3 = ixoff2+
            nbe*ixsmpl
       if (mode.eq.2) ixoff3 = ixoff2
C
       if (mode.eq.0) then

         do 860, j = 0,nbe-1
         do 860, i = 0,nbe-1
         ii = ixoff3+i*ixsmpl
            a(i,j) = bufi(ii,j)
860      continue
         else if (mode.eq.1) then
         do 861, j = 0,nbe-1
         do 861, i = 0,nbe-1
           ii = ixoff3+i*ixsmpl
            a(i,j) = bufi(ii-j,j)
861    continue
         else if (mode.eq.2) then
       do 862, j = 0,nbe-1
       do 862, i = 0,nbe-1
         ii = ixoff3+i*ixsmpl
```

```
                a(i,j) = bufi(ii+j,j)
      862       continue
                endif

                call svd (nm,m,n,a,sigma,.true.,u,
                     .true.,v,ierr,work)
                nsvd=nsvd+1

                if (ierr.ne.0) then
                 write (iw,20) ix,iy,ierr
      20         format (' TROUBLE. IX,IY,IERR=
                          ',3I6)
                 do 865, l = 0,nbe-l
                   write (iw,22) l,sigma(l)
      22           format (lx,i3,'th singular value =
                          ',E15.5)
      865        continue
                 do 866 i=0,ierr-l
                 sigma(i)=0.
      866        continue
                endif

      c     sort sigma(==singular values) in descending
                 order

                call sort (nbe,sigma,id)

                do 870, i = 0,nbe-l
                  temps(i,mode) = sigma(i)
                  idtemp(i,mode) = id(i)
      870       continue
                do 871, i = 0,nbe-l
                  do 871, J = 0,NBE-l
                    tempv(i,j,mode) = v(i,j)
                    tempu(i,j,mode) = u(i,j)
```

```
 871          continue

      c
      c      SIGMA(I,L(ID)): Ith SINGULAR VALUE
      5
 875          continue

              if (modeb.eq.0.or.modeb.eq.1.or.modeb.
                    eq.2) then
      10       kmode = modeb
              else if (modeb.eq.3) then
               call bmode(iw,nbe,temps,fc,dfc,kmode)
              else
               write (iw,*) ' HUI;MODEB IS NOT RIGHT'
      15       stop
              endif

               do 880, i = 0,nbe-1
              sigma(i) = temps(i,kmode)
      20      id(i) = idtemp(i,kmode)

               do 880, j = 0,nbe-1
                u(i,j) = tempu(i,j,kmode)
                v(i,j) = tempv(i,j,kmode)
      25 880   continue

      C      COMPUTE NEW A(I,J) ACCORDING TO CORING
                    FORMULAR(IFORM) FROM
      C      SIGMA, U, AND V.
      30

             call newaij (ir,iw,nbe,id,a,sigma,u,v,
                    fc,dfc,ratio
           1        ,iform,thrshl,coeff,power,fmin,
                    fmax,kmode)
      35
```

```
            if (modew.eq.-1) then
              do 885, j = 0,nbe-1
              do 885, i = 0,nbe-1
                a(i,j) = a(i,j)/wt(i)/wt(j)
 885          continue
            else if (modew.eq.1) then
              do 890, j = 0,nbe-1
              do 890, i = 0,nbe-1
                a(i,j) = a(i,j)*wt(i)*wt(j)
 890          continue
            endif

      C     UPDATE OUTPUT BUFFER : BUFO
      C     REPLACE NBR LINES AND ELEMENTS.

      C     NBR2 = (NBE-NBR)/2,NBR3=NBR2+NBR

            if(nbr.le.nbe/2) then
              ixoff4 = ixoff2+(nbe/2)*ixsmpl+nbr2*
                       ixsmpl
              if (kmode.eq.0) then
              do 895, j = 0,nbr-1
               jj = nbr2+j
                do 895, i = 0,nbr-1
                ii = ixoff4+i*ixsmpl
                    bufo(ii,jj) = bufo(ii,jj)+
                                  a(nbr2+i,jj)
 895          continue
              else if (kmode.eq.1) then
              do 896, j = 0,nbr-1
               jj = nbr2+j
                do 896, i = 0, nbr-1
                ii = ixoff4+i*ixsmpl
                  bufo(ii,jj) = bufo(ii,jj)+
                                a(nbe/2-nbr+i+j,jj)
```

```
      896       continue
                    else if (kmode.eq.2) then
                  do 897, j = 0,nbr-1
                    jj = nbr2+j
                      do 897, i = 0,nbr-1
                      ii = ixoff4+i*ixsmpl
                         bufo(ii,jj) = bufo(ii,jj)+
                               a(nbe/2+i-j,jj)
      897       continue
                   endif
      c               end of kmode ?

                else if(nbr.eq.nbe) then
                  if (kmode.eq.0) then
                    ixoff4=ixoff2+(nbe/2)*ixsmpl
                    do 995, j = 0,nbr-1
                    jj = nbr2+j
                    do 995, i = 0,nbr-1
                    ii = ixoff4+i*ixsmpl
                       bufo(ii,jj) = bufo(ii,jj)+a(i,j)
      995           continue
                  else if (kmode.eq.1) then
                     ixoff4=ixoff2+nbe*ixsmpl
                     do 996, j = 0,nbr-1
                     jj = nbr2+j
                     do 996, i = 0,nbr-1
                     ii = ixoff4+i*ixsmpl
                       bufo(ii-j,jj) = bufo(ii-j,jj)+a(i,j)
      996            continue
                  else if (kmode.eq.2) then
                     ixoff4=ixoff2
                     do 997, j = 0,nbr-1
                     jj = nbr2+j
                     do 997, i = 0,nbr-1
                     ii = ixoff4+i*ixsmpl
```

```
                bufo(ii+j,jj) = bufo(ii+j,jj)+a(i,j)
997           continue
            endif
c                 end of kmode ?
          else
          write(iw,*) ' nbr should be .le.(nbe/2).
                   or .eq.nbe'
          stop
          endif
c           end of nbr ?

900     continue

C       WRITE LINES OUT TO DISK (AFTER NN LINES, MM
              BLOCKS ARE PROCESSED)

          do 905, j = nbr2,nbr3-1
            lineo = line2+j*iysmpl
            write (iuo,rec=lineo) (bufo(i,j),
                       i=0,ne-1)
905       continue

910     continue

C       WRITE OUT REMAINING LINES

          if (lextra.gt.0) then
            line3 = nl-lextra+1
            do 915, iy = 0,lextra-1
              irec = line3+iy
              read (iui,rec=irec) (bufi(i,0),i=0,ne-1)
              write (iuo,rec=irec) (bufi(i,0),i=0,ne-1)
915           continue
          endif
```

```
      return
      end

C-----------------------------------------------------

      subroutine newaij (ir,iw,nbe,id,a,sigma,u,v,
     1                   fc,dfc,ratio
     1,iform,thrshl,coeff,power,fmin,fmax,kmode)

       logical first
      dimension a(0:nbe-1,0:nbe-1)
      dimension sigma(0:nbe-1),id(0:nbe-1)
      dimension u(0:nbe-1,0:nbe-1),
     1          v(0:nbe-1,0:nbe-1)
      dimension fc(0:39,0:2),dfc(0:39,0:2),
     1          ratio(0:39,0:2)

      data first/.true./

      if(first) then
      write (iw,8888) iform,thrshl,power,fmin,
     1          fmax,coeff,kmode
 8888    format (' newaij: iform,t1,p,t2,c,
     1          kmode = ',i5,4f6.2,i5)
      first=.false.
      endif

     do 100, j = 0,nbe-1
       do 100, i = 0,nbe-1
         a(i,j) = 0.
  100 continue

      if(iform.eq.6) then
      call iform6(ir,iw,nbe,id,a,sigma,u,v,
     1          fc,dfc,ratio
```

```
     1,iform,thrshl,coeff,power,fmin,fmax,kmode)
        endif

        return
        end
c-------------------------------------------------

        subroutine iform6 (ir,iw,nbe,id,a,sigma,u,v,
                           fc,dfc,ratio
     1,iform,thrshl,coeff,power,fmin,fmax,kmode)

        dimension a(0:nbe-1,0:nbe-1)
        dimension sigma(0:nbe-1),id(0:nbe-1)
        dimension u(0:nbe-1,0:nbe-1),v(0:nbe-1,
                           0:nbe-1)
        dimension fc(0:39,0:2),dfc(0:39,0:2),
                           ratio(0:39,0:2)

        delf = fmax - fmin

        do 120, 1 = 0,nbe-1

c       depending on IFORM choose boost level

        ff = 1.

        if (sigma(1).gt.0.) then
          zz = (sigma(1)-fc(1,kmode))/dfc(1,kmode)

          if (zz.le.thrshl) then
            ff = fmin
          else if (zz.gt.thrshl) then
            arg = coeff*((zz-thrshl)**power)
            if (arg.le.0.000000001) then
              delf = delf*(1.-arg)
```

```
                else if (arg.gt.0.000000001.and.arg.
                          le.10.) then
                  delf = delf*exp(-arg)
                else if (arg.gt.10.) then
                  delf = delf
                endif
     c              end of arg ?

                ff = fmin + delf
              endif
     c              end of (zz...

            else if(sigma(1).eq.0.) then
            ff=1.

            else if(sigma(1).lt.0.) then
              write (iw,505) ix,iy,1,sigma(1)
     505      format (' ix,iy,1,sigma(1)',3i5,e15.5)
              f = 1.
            endif
     c      end of (sigma(1)...

            do 110, j = 0,nbe-1
             do 110, i = 0,nbe-1
               a(i,j) = a(i,j)+ff*sigma(1)*u(i,id(1))*
                          v(j,id(1))
     110    continue
     120    continue
              return
            end
     c-------------------------------------------------

            subroutine bmode (iw,nbe,temps,fc,dfc,kmode)

     C      SELECT THE MODE WHICH IS THE BEST
```

```
      dimension temps(0:39,0:2)
      dimension fc(0:39,0:2),dfc(0:39,0:2)
      dimension lzero(0:2),modeid(0:2)
      dimension zval(0:2)

C     GET THE ORDER WHICH IS CLOSE TO NOISE VALUE

      do 110, mode = 0,2
        lzero(mode) = 0
        do 100, l = 0,nbe-1
          zz = (temps(l,mode)-fc(l,mode))/
                        dfc(l,mode)
          if (abs(zz).lt.3.5) then
              lzero(mode) = l
            go to 110
            endif
  110   continue
  110 continue

C     DETERMINE THE MODE WHICH HAS THE LOWEST ORDER
C     SEE IF ANY OF THE TWO ARE THE SAME

      lmin = nbe-1
      do 120, mode = 0,2
        if (lzero(mode).le.lmin) then
          lmin = lzero(mode)
        endif
  120 continue

      lflag = 0
      do 130, mode = 0,2
        if (lzero(mode).eq.lmin) then
          modeid(lflag) = mode
          lflag = lflag+1
```

```
            endif
      130   continue

            if (lflag.eq.1) then
              kmode = modeid(0)

            else if (lflag.eq.2) then
              call clrx(2,zval)
              do 140, k = 0,1
                kk = modeid(k)
                do 140, i = 0,1
                  zval(k) = zval(k)+temps(i,kk)-
                            fc(i,kk))/dfc(i,kk)
      140     continue

              kmode = modeid(0)
                if (zval(1).gt.zval(0)) kmode = modeid(1)

            else if (lflag.eq.3) then

              if (modeid(0).eq.0) then
                kmode = 0

              else if (modeid(0).eq.1) then
              zmax = -999.
              kmode = -1
              do 150, k = 0,2
                zz = (temps(0,k)-fc(0,k))/dfc(0,k)
                if (zz.gt.zmax) then
                kmode = k
                endif
      150     continue

            else
              call clrx(3,zval)
```

```
            do 160, k = 0,2
              do 160, l = 0,1
              zval(k) = zval(k)+(temps(l,k)-fc(l,k))/
                           dfc(l,k)
  160         continue

              zmax = -999.
              kmode = -1
              do 165, k = 0,2
                if (zval(k).gt.zmax) then
                kmode = k
                endif
  165         continue

            endif

            if (kmode.eq.-1) then
              write (iw,170) (zval(k),k = 0,2)
  170         format (' WARNING !!! BMODE: LFLAG = 3,
                           ZVAL =',3F10.2)
              kmode = 0
            endif

          endif

          return
          end

C-----------------------------------------------------

          subroutine norm(ne,nl,buf,denom)

          dimension buf(0:ne-1,0:nl-1)

          do 1 j=0,nl-1
```

```
            do 1 i=0,ne-1
            buf(i,j)=buf(i,j)/denom
      1      continue

            return
            end
      c-------------------------------------------------

            subroutine nfile(ir,iw,iun,nbe,ixsmpl,iysmpl,
     10                     fc,dfc,ratio)

            character*32       text,fname(0:2)

            dimension fc(0:nbe-1,0:2),dfc(0:nbe-1,0:2),
     15                     ratio(0:nbe-1,0:2)
            dimension iun(0:2)
      c      dimension mode(0:2)

            text='svd noise file for     0 degree'
     20     call ascnam(ir,iw,text,fname(0))
            call ascopn(iun(0),fname(0),'old',' ')

            text='svd noise file for    45 degree'
            call ascnam(ir,iw,text,fname(1))
     25     call ascopn(iun(1),fname(1),'old',' ')

            text='svd noise file for   135 degree'
            call ascnam(ir,iw,text,fname(2))
            call ascopn(iun(2),fname(2),'old',' ')
     30
            do 801 ifile = 0,2
            read(iun(ifile),*) nbe,ixsmpl,iysmpl
      c114      format(3i)
            write(iw,115) fname(ifile)
     35 115     format(' noise file:',a32,/
```

```
     1 5x,'order',5x,' mean',10x,'sigma',5x,'ratio')

               do 802 l=0, nbe-1
         read(iun(ifile),*) iorder
     5  1,fc(l,ifile),dfc(l,ifile),ratio(l,ifile)
         write(iw,116) iorder,fc(l,ifile),dfc(l,ifile),
                       ratio(l,ifile)
    116     format(1x,i5,3e15.5)
    802     continue
    10  c        end of loop l
            close(unit=iun(ifile))

    801       continue
    c        end of loop ifile
    15
            return
            end
```

20

25

30

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CLAIMS:

1. A method of processing an image in a digital computer for sharpening the image, comprising the steps of:

a. generating a non-linear gain function based upon the measured statistics of the SVD singular values for image noise, said non-linear gain function being characterized by boosting factors applicable wherever there is a high signal-to-noise ratio;

b. filtering the digital image to produce a detail image and a low pass filtered image;

c. dividing the detail image into blocks;

d. transforming the blocks employing an SVD transformation to produce singular vectors and arrays of singular values;

e. applying the non-linear gain function to the arrays of singular values to produce arrays of modified singular values whereby to boost those singular values corresponding to a higher signal-to-noise ratio;

f. performing an inverse SVD on the singular vectors with modified singular values to produce blocks of processed detail image values;

g. combining the processed image detail values with the low pass filtered image values to produce a sharpened digital image.

2. The method of processing a digital image claimed in claim 1, wherein said step of generating a non-linear gain function comprises the steps of:

a. producing a noise digital image having only a noise component;

b. filtering the noise digital image to produce a noise detail image and a low pass filtered

noise image;

c. dividing the noise detail image into a plurality of blocks;

d. performing an SVD transformation on the blocks of the noise detail image to produce singular vectors and an array of singular values for each block;

e. calculating the means and standard deviations for respective singular values of the blocks;

f. generating a non-linear gain function for each of the singular values based upon the respective means and standard deviations.

3. The method of processing a digital image claimed in claim 1, further including the steps of:

a. operating the method in a plurality of stages, wherein each stage employs blocks overlapping with blocks of another stage;

b. generating the processed digital image from the average values of the processed image values from the overlapping blocks, whereby the processed image is generated without visible block structure.

4. The method of processing a digital image claimed in claim 1, further including the steps of:

a. operating the method in a stage, wherein said stage employs an image detail signal representing a certain pass band of spatial frequencies, and generating the process digital image from the processed detail signal from said stage, whereby noise from different sources characterized by certain spatial frequency content is effectively removed from the image.

5. The method of processing a digital image claimed in claim 4, further including the steps of:

a. operating the method in a plurality of stages, wherein each stage employs blocks overlapping with blocks of another stage; and

b. generating the processed digital image from the average values of the processed image values from the overlapping blocks, whereby the processed image is generated without a visible block-like structure.

6. The method of processing a digital image claimed in claim 1, further including the steps of:

a. dividing the detail image into blocks having diagonally oriented edges;

b. performing the SVD transform on the diagonally oriented blocks;

c. employing the blocks having the highest singular values for processing the image.

7. The method of processing a digital image claimed in claim 1, wherein the digital image is a color digital image, and wherein the method is applied to each color component of the digital image to produce a processed color digital image.

8. The method of processing a digital image claimed in claim 1, wherein the image is a color digital image having a luminance component and two color components, wherein the method is applied to the luminance component of the digital image to produce a processed color digital image.

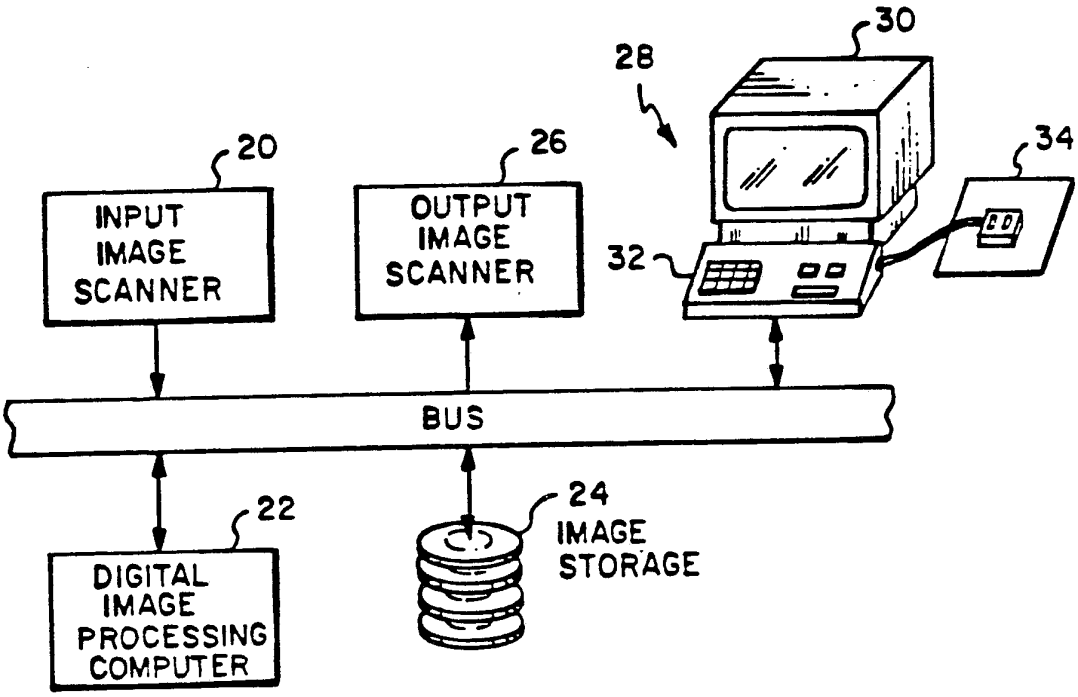

30
28
20
26
34
INPUT IMAGE SCANNER
OUTPUT IMAGE SCANNER
32
BUS
22
24
IMAGE STORAGE
DIGITAL IMAGE PROCESSING COMPUTER

FIG. 1

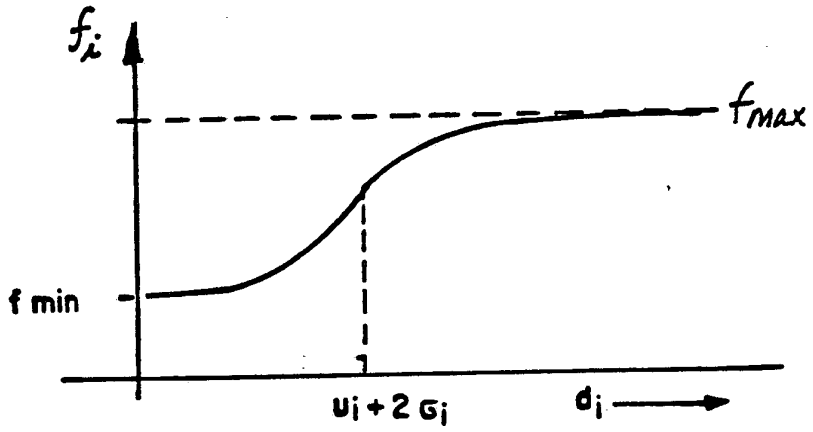
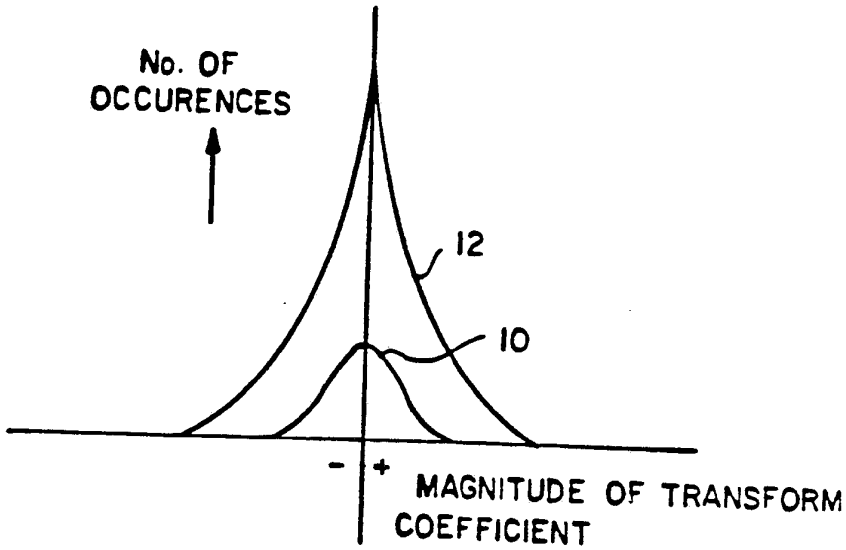

f_i
f_{max}
f min
$u_i + 2\sigma_i$
d_i

FIG. 6



PRIOR ART

FIG. 2

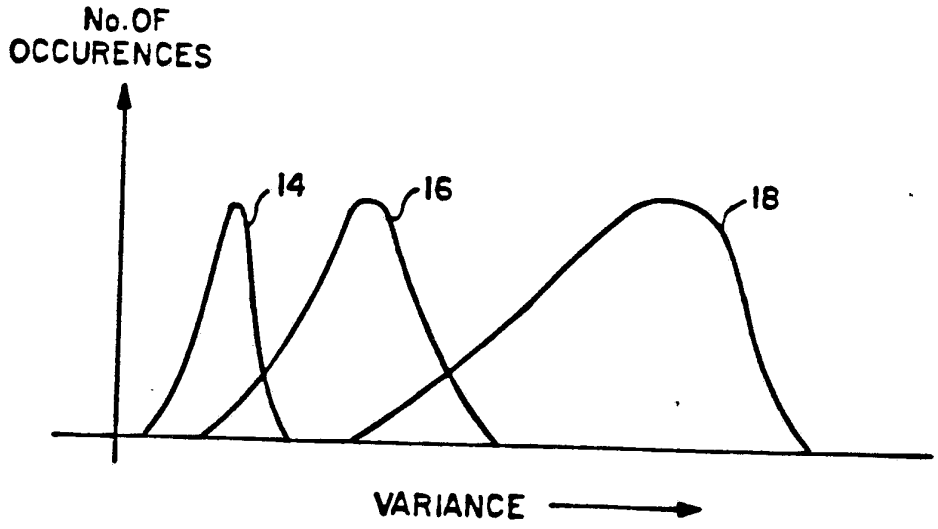


FIG. 3

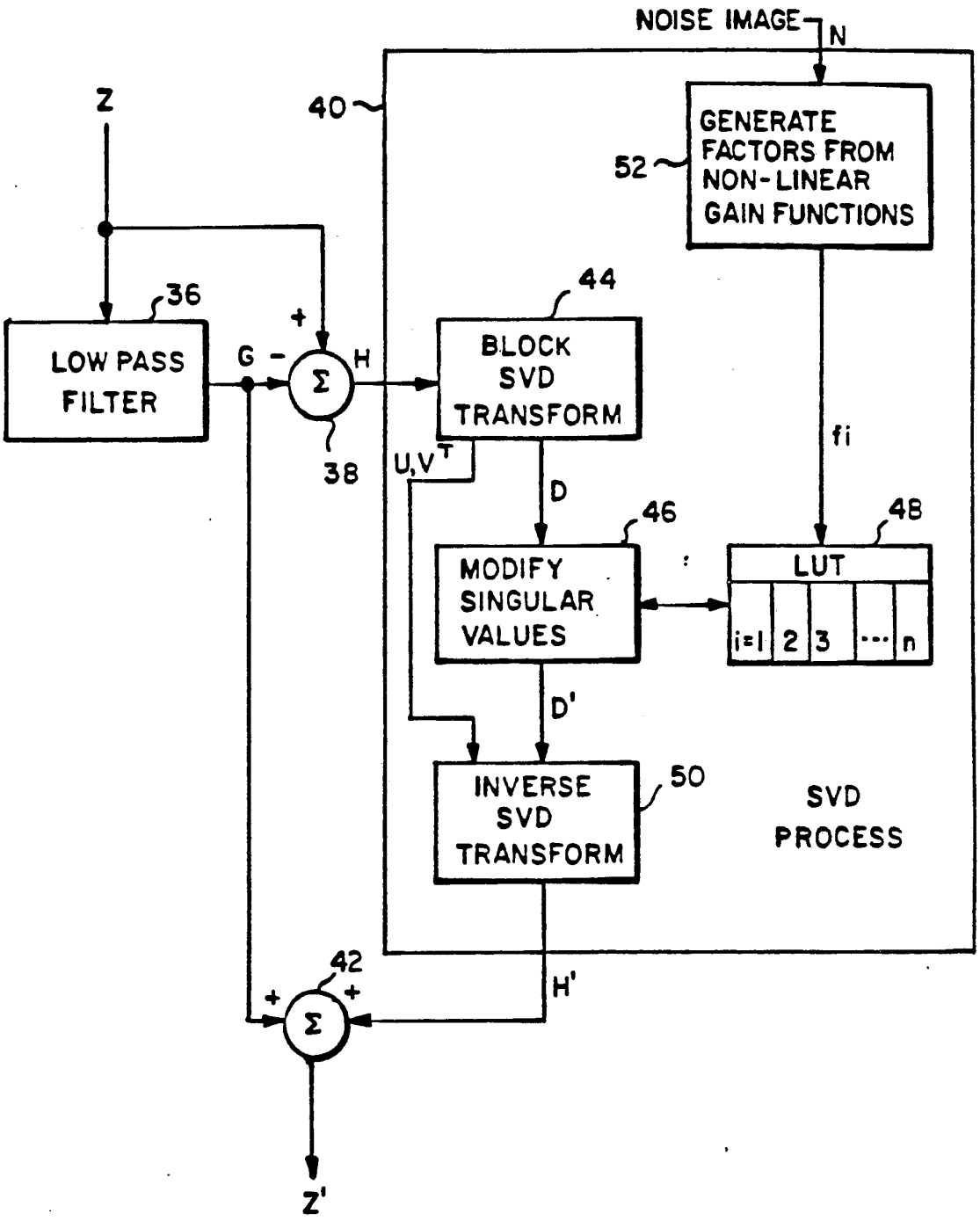

NOISE IMAGE
N
Z
40
GENERATE FACTORS FROM NON-LINEAR GAIN FUNCTIONS
52
36
LOW PASS FILTER
G
+
-
H
Σ
38
44
BLOCK SVD TRANSFORM
fi
U,V^T
D
46
48
MODIFY SINGULAR VALUES
LUT
i=1
2
3
...
n
D'
INVERSE SVD TRANSFORM
50
SVD PROCESS
42
H'
Z'

FIG. 4

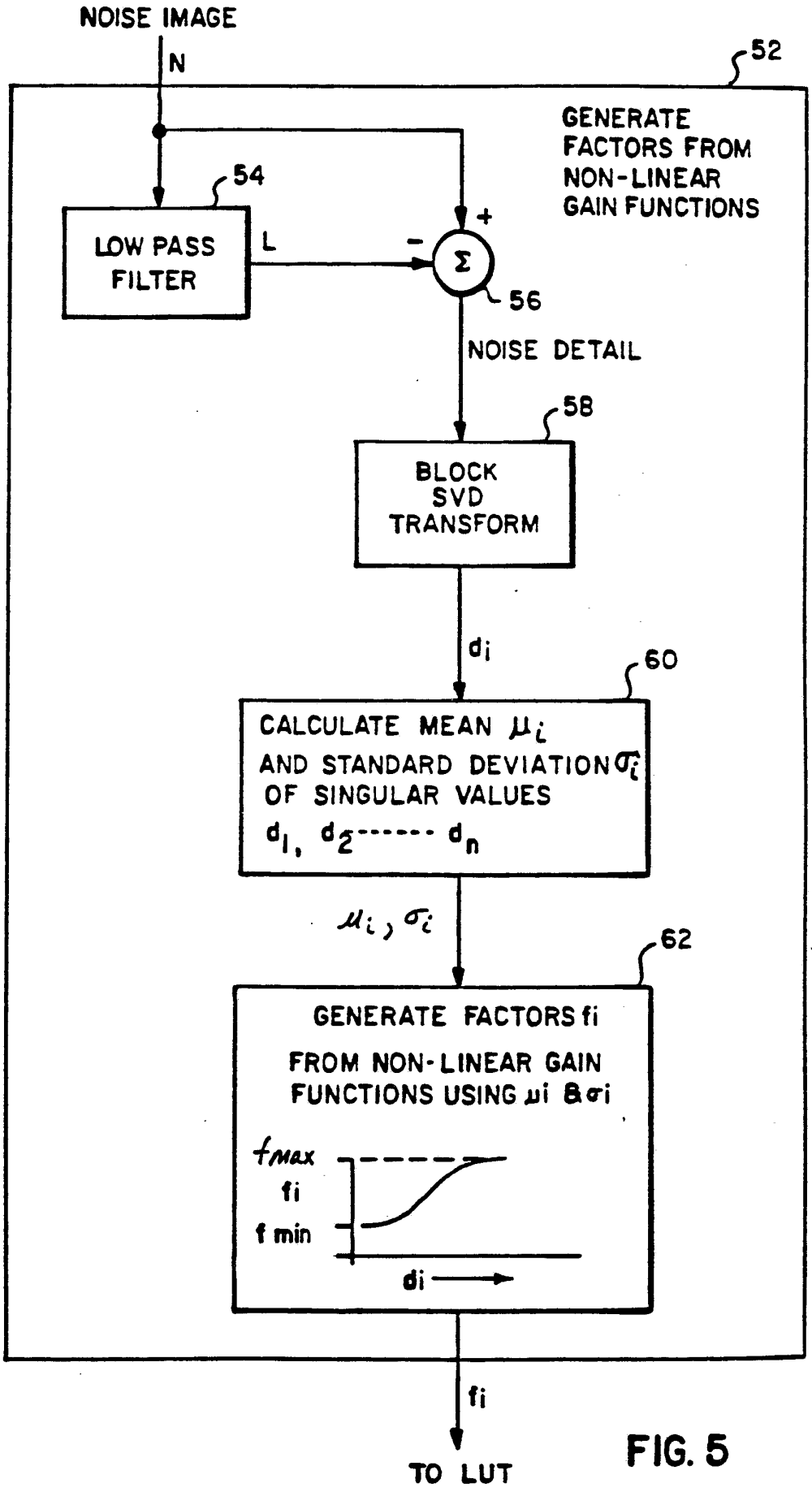

NOISE IMAGE
N
52
GENERATE FACTORS FROM NON-LINEAR GAIN FUNCTIONS
54
LOW PASS FILTER
L
+
-
Σ
56
NOISE DETAIL
58
BLOCK SVD TRANSFORM
di
60
CALCULATE MEAN μi AND STANDARD DEVIATION σi OF SINGULAR VALUES
d1, d2 ------ dn
μi, σi
62
GENERATE FACTORS fi FROM NON-LINEAR GAIN FUNCTIONS USING μi & σi
fmax
fi
f min
di
fi
TO LUT

FIG. 5

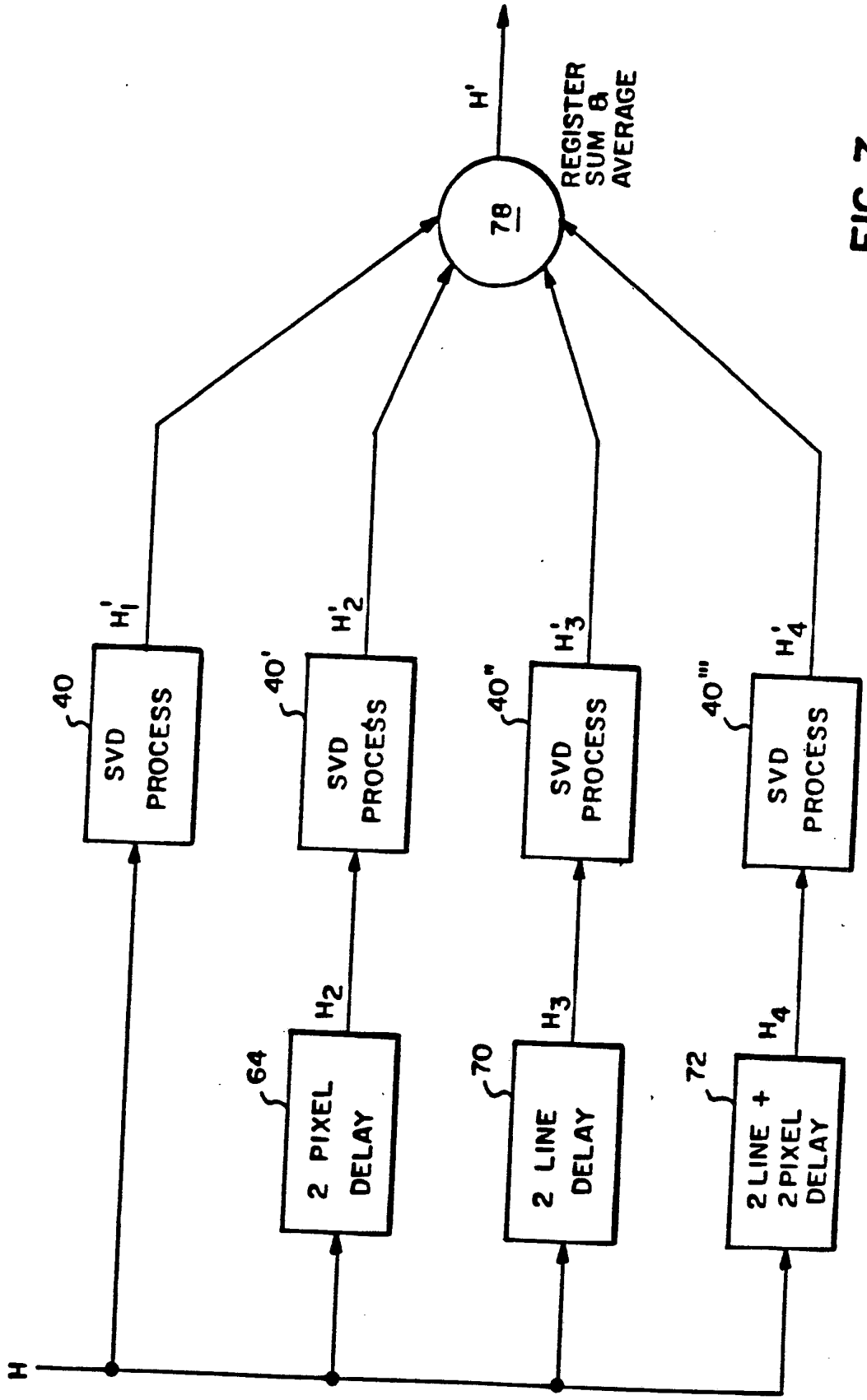

H'
REGISTER SUM & AVERAGE
78
H'1
H'2
H'3
H'4
40
40'
40"
40'''
SVD PROCESS
SVD PROCESS
SVD PROCESS
SVD PROCESS
H2
H3
H4
64
70
72
2 PIXEL DELAY
2 LINE DELAY
2 LINE + 2 PIXEL DELAY
H

FIG. 7

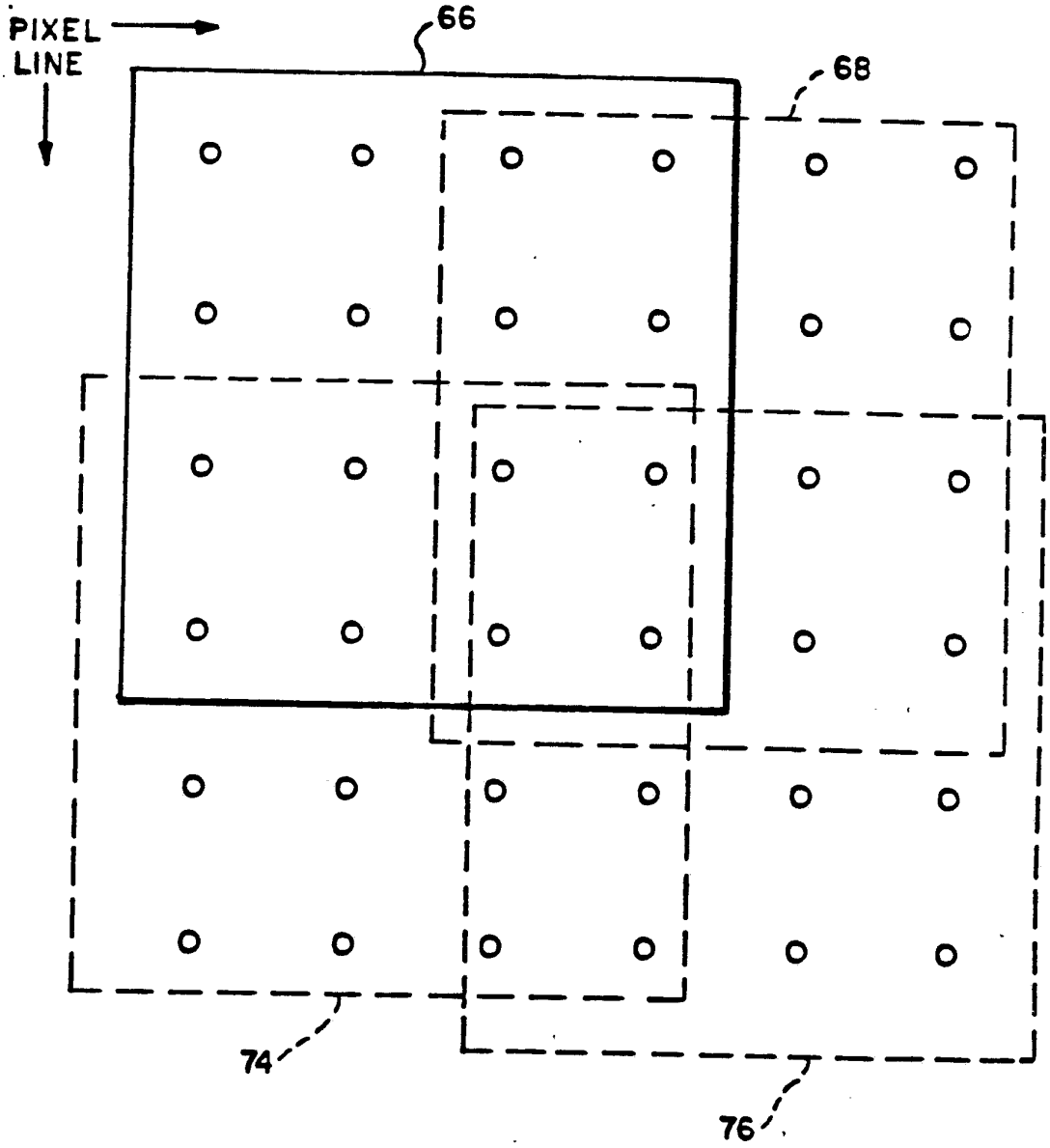


FIG. 8

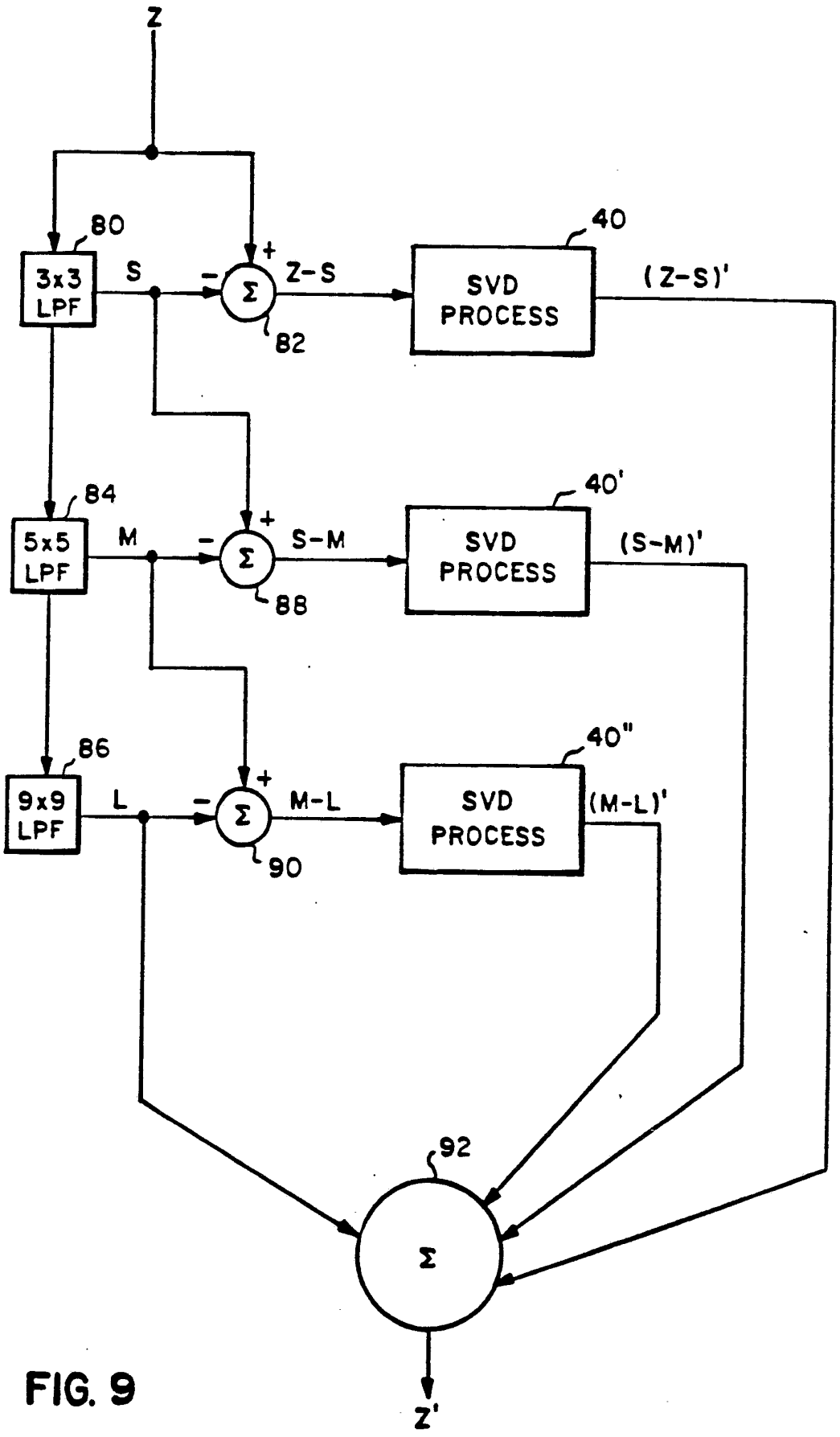

Z
80
3x3 LPF
S
+
−
Σ
Z-S
82
40
SVD PROCESS
(Z-S)'
84
5x5 LPF
M
S-M
88
40'
SVD PROCESS
(S-M)'
86
9x9 LPF
L
M-L
90
40"
SVD PROCESS
(M-L)'
92
Σ
Z'

FIG. 9

1	2	1
2	4	2
1	2	1

FIG. 10a

1	0	2	0	1
0	0	0	0	0
2	0	4	0	2
0	0	0	0	0
1	0	2	0	1

FIG. 10b

1	0	0	0	2	0	0	0	1
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
2	0	0	0	4	0	0	0	2
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1	0	0	0	2	0	0	0	1

FIG. 10c

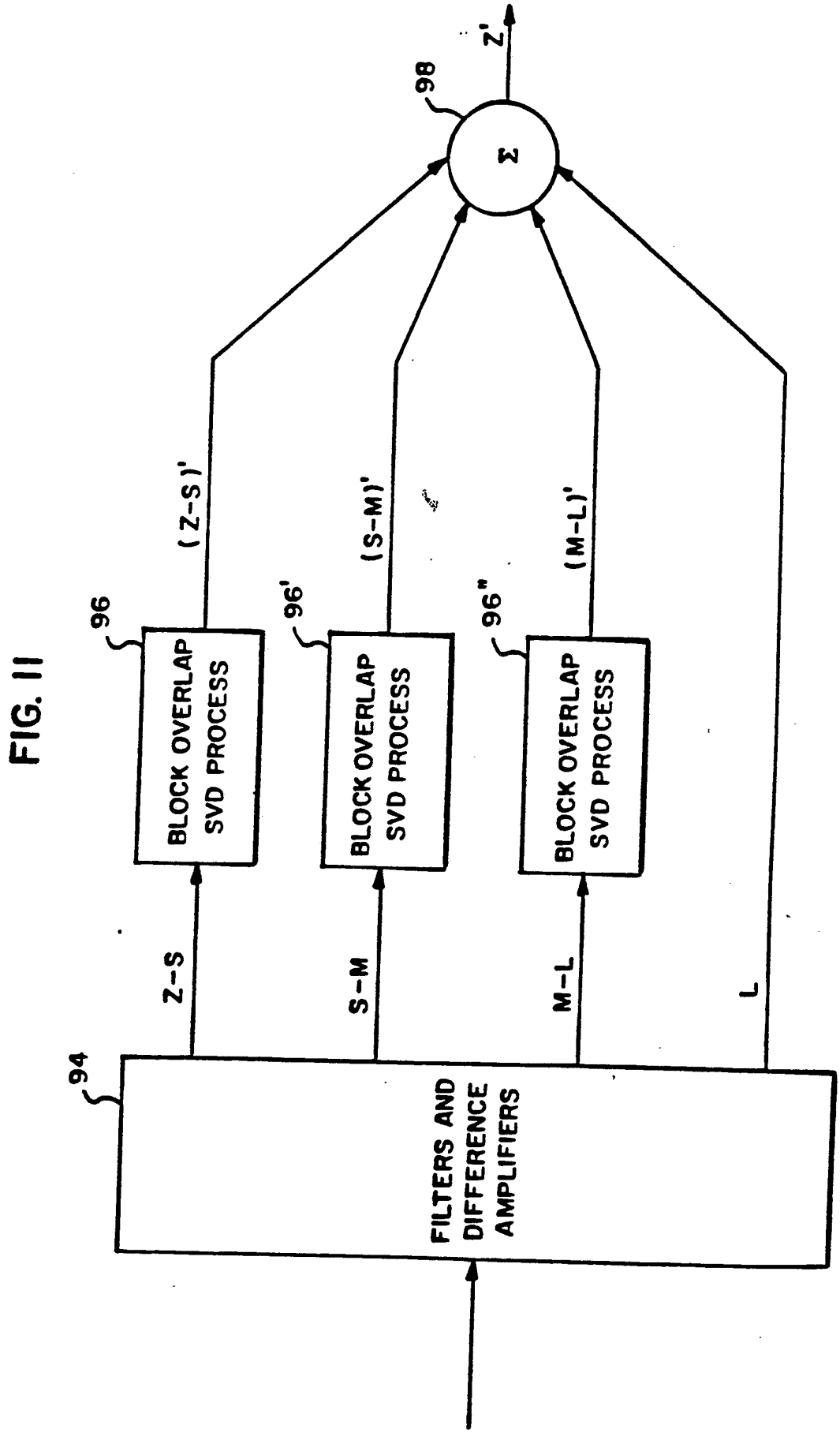

FILTERS AND DIFFERENCE AMPLIFIERS
94
Z-S
S-M
M-L
L
BLOCK OVERLAP SVD PROCESS
96
BLOCK OVERLAP SVD PROCESS
96'
BLOCK OVERLAP SVD PROCESS
96"
(Z-S)'
(S-M)'
(M-L)'
Σ
98
Z'

FIG. 11

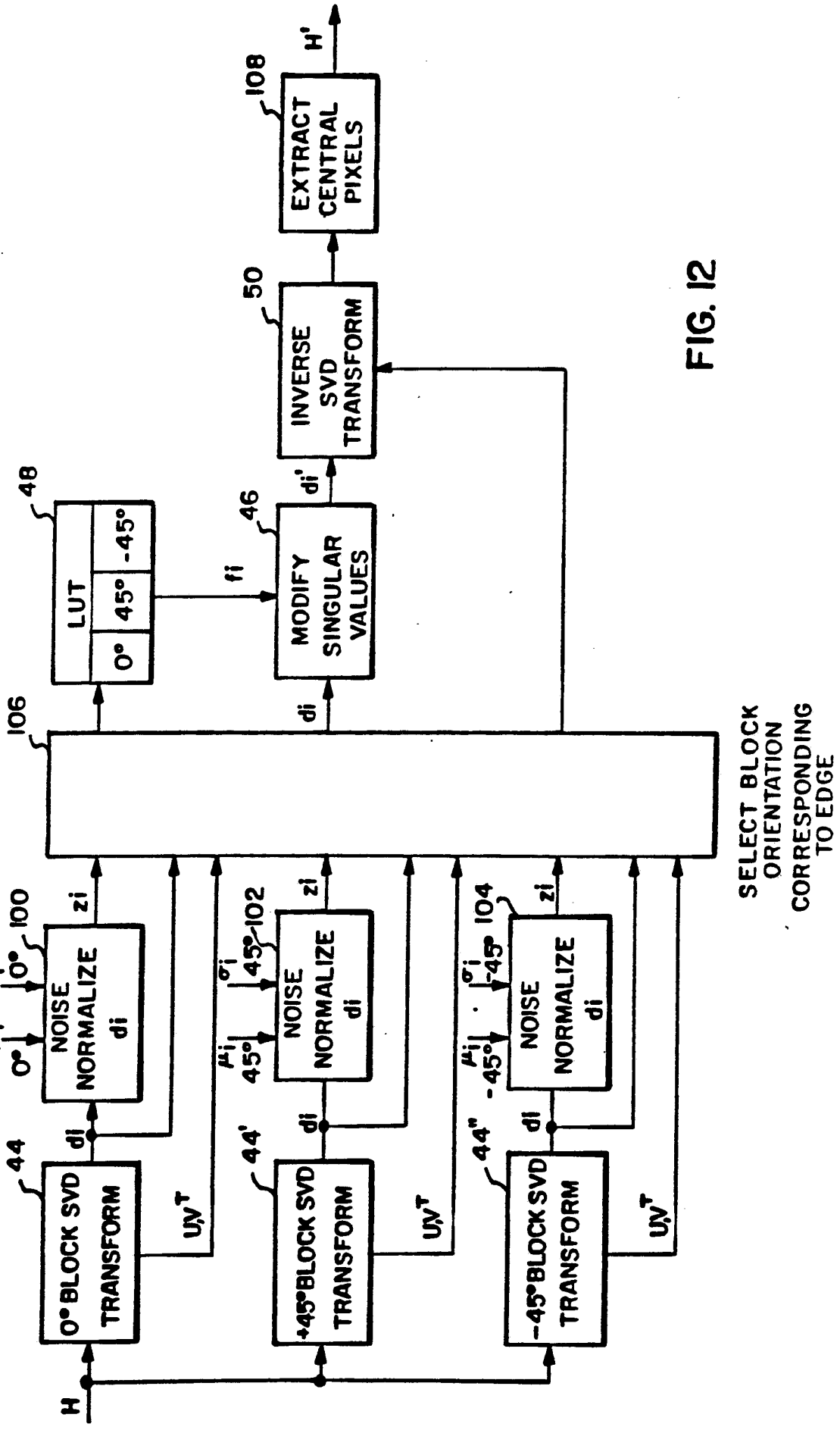

H
0° BLOCK SVD TRANSFORM
+45° BLOCK SVD TRANSFORM
-45° BLOCK SVD TRANSFORM
44
44'
44"
di
$U_i V_i^T$
NOISE NORMALIZE di
100
102
104
μ_i
σ_i
0°
45°
-45°
zi
SELECT BLOCK ORIENTATION CORRESPONDING TO EDGE
106
LUT
0°
45°
-45°
48
fi
MODIFY SINGULAR VALUES
46
di'
INVERSE SVD TRANSFORM
50
EXTRACT CENTRAL PIXELS
108
H'

FIG. 12

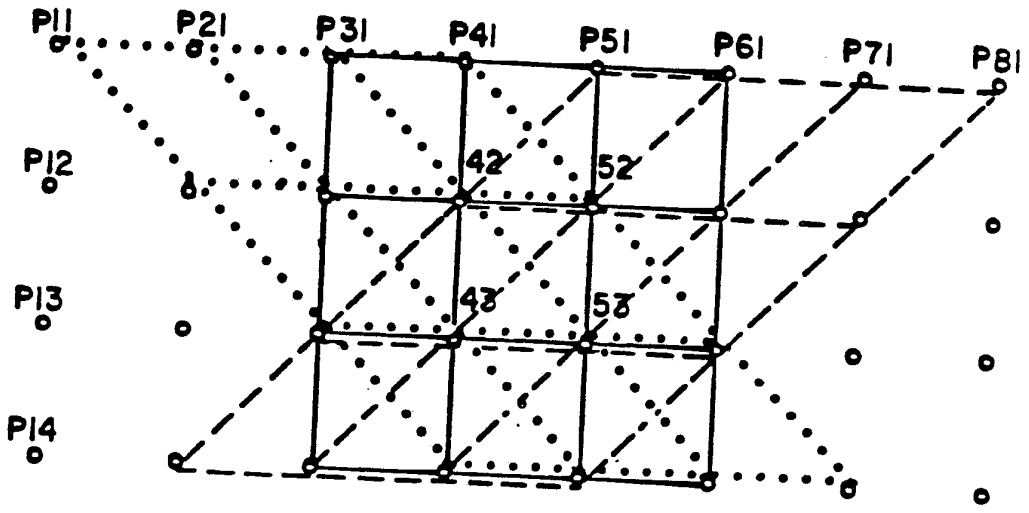


FIG. 13

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 89/05701

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: G 06 F 15/68

II. FIELDS SEARCHED

Minimum Documentation Searched [7]	
Classification System	Classification Symbols
IPC[5]	G 06 F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4672437 (LAWRENCE A. CASPER) 9 June 1987 see column 3, line 38 - column 4, line 31 --	1
A	WO, A, 85/00907 (EASTMAN KODAK COMPANY) 28 February 1985 see pages 1-12 --	1-8
A	IEEE Transactions on Pattern Analysis and Machine Intelligence PAMI-9, No. 1, January 1987, IEEE, (New York, US), Ari Nieminen et al.: "A new class of detail-preserving filters for image processing", pages 74-90 see the whole document	1

---

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
21st April 1990	30. 05. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	E.W. HECK

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 8905701 SA 33764

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 15/05/90
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4672437	09-06-87	None	
WO-A- 8500907	28-02-85	US-A- 4553165	12-11-85
		EP-A,B 0151614	21-08-85
		JP-T- 60502023	21-11-85