USE OF THE VARIABLE GAIN SETTINGS ON SPOT

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ABSTRACT

To collect image data from all parts of the Earth's surface, satellite imaging systems must be designed for targets with both dark and bright reflectance values. Often the brightness or digital number (DN) range of satellite image data is less than optimal and uses only a portion of the available values (0–255) because the range of reflectance values is small. Except for SPOT (System Probatoire d'Observation de la Terre), most imaging systems have been designed with only two gain settings, normal and high. The SPOT imaging system has the capability to collect image data using one of eight different gain settings. With the proper procedure, this allows the brightness or reflectance resolution, which is directly related to the range of DN values recorded, to be better optimized for any given site as compared to using a single set of gain settings everywhere.

The island of Hawaii was used as the test site and normal/standard– (5,6,5) and high/maximum– (8,8,8) gain SPOT images were collected simultaneously using the HRV1 and HRV2 (high resolution visible) imaging systems, respectively. Old Landsat MSS (multispectral scanner) data were used to predict in advance the optimum SPOT gain settings for the given site. The original SPOT images were processed using spatial filtering and first–difference algorithms to enhance the local detail. The high–gain data, which had a gain increase of approximately 2.2 for bands XS1 and XS3 and 1.7 for band XS2, showed detail through DN changes that are equivalent to less than half a DN and could not be shown in the normal gain data. The results indicate that the normal/standard gain settings currently being used may be to low for many areas.

INTRODUCTION

The use of digital images recorded by imaging systems on board orbiting satellites is becoming more widespread. Digital image data have been widely available since 1972 when the first Landsat multispectral scanner (MSS) satellite, known as ERTS–1, was launched. The Landsat MSS system was followed by the Landsat Thematic Mapper (TM) which was launched in 1982. The TM data have improved spatial and spectral resolution as compared to the older MSS data. The MSS data have approximately 75 meter spatial resolution and four spectral bands; the TM data have approximately 30–meter spatial resolution and six spectral bands, plus a 120–meter resolution thermal band.

With the launching of SPOT (System Probatoire d'Observation de la Terre) in early 1986, digital image data collected from space and available to the general public became an international enterprise. SPOT data have improved spatial resolution as

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compared to the Landsat TM data (three 20-metermultispecspectral bands and a 10-meter panchromatic band). With the need to collect image data from all parts of the Earth's surface, imaging systems must be designed to image targets with both dark and bright albedo values. For example, forested and water-covered areas have dark albedos while deserts and snow covered areas have bright albedos. Usually, because of this requirement the actual digital number (DN) range of images collected from satellites is less than optimal, filling only a portion of the available range of 0 to 255 on Landsat TM and SPOT. Exceptfor SPOT, most imaging systems have been designed with only two gain settings, normal and high. The gain settings allow the brightness or reflectance resolution to be increased or decreased, affecting the DN range within an image. The high gain setting on Landsat has not readily been available in an operational sense and is conconsidered a special request.

Generally, the standard gain settings are used to collect data in areas with both dark and bright albedos. This means that the gain and offset values used by the imaging system to convert radiance values in analog form to digital numbers are constant for a given band on a given satellite, regardless of the target being imaged or the application.

The SPOT imaging system has the capability to collect digital image data using one of eight different gain settings. Three are higher than normal and four are lower than normal (Courtois, 1984). With the proper selection, the brightness or reflectance resolution, which is directly related to the range of DN values, for any site can be optimized.

The gain settings required to optimize the brightness or reflectance range of a particular area within the available DN range will be influenced by (1) the range of the reflectance values within the spectral band for the area of interest, (2) the Sun elevation, and 3) atmospheric conditions. Of course, the topography/slopes present in the area will also affect the brightness range. The objective in this paper is to show the results of the use of the variable gain settings of SPOT. The optimal gain settings for the given test site were predicted using Landsat MSS data and an inter-sensor calibration technique developed by the author. This calibration procedure is the subject of another paper and is outside the scope of this paper.

TEST SITE and DATA CHARACTERISTICS

The large island of Hawaii was used as the test site due to the generally dark reflectance of the various cover types in the area (volcanic rocks, dense vegetation, and ocean water). A low reflectance site was desired to test the variable gain capability in case the predicted results were not as expected because a dark test site would allow for possible errors by not causing instrument saturation. However, there were areas with high reflectance values in the image area. The center of the image area is just to the right of the Mauna Loa volcano and includes both barren dark volcanic rocks and highly to sparsely vegetated areas. About 5-7 percent of the pixels within the SPOT image are ocean water and approximately 43 percent are clouds. The SPOT 20-meter multispectral (XS) data were collected on June 27, 1987. The world reference scene number is (K,J) equal to (473,311). SPOT XS data with both the normal (5,6,5) and maximum/high (8,8,8) gain settings were collected simultaneously using the HRV1 and HRV2 (high-resolution visible) imaging systems, respectively. The Sun elevation during data collection was 67.8 degrees with an azimuth of 75.7 degrees. The digital data delivered were in level 1A format.

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The Landsat MSS data used to compute the optimal SPOT gain settings were collected on February 11, 1973. The Landsat path and row numbers are 67 and 46, respectively; the scene ID is 1203–2018000. The normal gain settings were used. The Sun elevation during data collection was 41.0 degrees with an azimuth of 132.0 degrees.

DISCUSSION

The Landsat MSS data were used to compute the approximate minimum, average, and maximum reflectance values within each spectral band for the area of interest. These reflectance values were computed by first removing the affects of the gain and offset values used by Landsat (i.e., converted from DN to radiance). The data were then corrected for first–order atmospheric scattering and Sun elevation affects (Chavez, 1988). These computed reflectance values were then adjusted to the Sun elevation of the SPOT data and a first–order atmospheric scattering effect was added. Finally, the various SPOT gain settings were applied to these new radiance values to predict the equivalent SPOT DN values. This approximating procedure was used to identify the highest gain settings that could be used on the SPOT XS bands without saturating the maximum reflectance of interest to a DN value of 255. For the Hawaii test site the maximum settings available were identified as the optimum ones to use. In fact, the computed results indicated that higher gain settings could have been used for XS1 and XS2 without saturation at the area of maximum reflectance. The original test reflectance targets did not include clouds; however, interesting results were seen in the final SPOT data which had about 43 percent clouds.

The SPOT imaging system has eight different gain settings available; the ratio of any two consecutive gain settings is equal to 1.3 (Begni, G., Boissin, B., and Perbos, J., 1985). The value of a particular gain is computed as follows:

$$\mathrm{GAIN} = 1.3(M-3);\ M = 1,8 \qquad (1)$$

Notice that for M = 3 the gain value of 1.0 is used, which translated to no gain except for the absolute calibration values. The normal/standard gain settings for SPOT are M equals five for bands XS1 and XS3 and M equals six for band XS2 (Begni, G., Boissin, B., and Perbos, J., 1985).

The advantage of using the highest possible gain settings is that the ability to record incremental differences in reflectance levels is improved. This has the affect of increasing the output data range to eight or nine bit data, rather than the six– to seven–bit range usually seen. The dynamic range improvement is not limited to only dark areas; the incremental DN difference between the normal– and high–gain images can be seen at all brightness levels.

RESULTS

The high/maximum gain setting images show brightness detail that would be the equivalent of less than half a DN change in the normal/standard gain setting images. The differences between the normal (M = 5,6,5) and high (M = 8,8,8) gains are approximately 2.2 for bands XS1 and XS3 and 1.7 for band XS2. Subareas representing dark, midtone, and bright regions were used to statistically and visually compare and evaluate the differences between the normal– and high–gain images. The image products used in the analysis included: (1) the original, (2) high–pass filtered (HPF), and (3) vertical first–difference images. The variance and percentages at midrange of these images were compared. For visual analysis, the data had hard linear contrast stretches applied before generating prints. It is interesting to note that the number of pixels saturated to a DN value of 255 in the high–gain data for XS1, XS2, and XS3 were 33.9, 25.9, and 30.0 percent, respectively. This compared to 14.1, 5.6, and 0.8 for the normal gain data. Since there is approximately 43 percent cloud cover, determined by saturating the cloud pixels to 255 with an interactive stretch program and identifying the DN location in the image histogram, even in the high-gain mode all the clouds were not saturated.

Shown below for both the normal- and high-gain three SPOT XS bands are the standard deviation and midrange percentage of the original image, 11 by 11 high-pass filter (HPF), 21 by 21 HPF, and vertical first-difference for the dark Mauna Loa subarea. The percent of pixels with DN values at midrange are shown because these values are an indication as to the amount of subtle changes present in the image, which correspond to local detail.

TABLE 1. Standard deviations and mid-range percentages for three normal- and high-gain SPOT XS bands, Mauna Loa, Hawaii

IMAGE	ORG SD	11 x 11 SD	21 x 21 SD	1st DIFF SD	MID RNG% 11 x 11	MID RNG% 21 x 21	MID RNG% 1st DIFF
Normal XS1	5.0	6.3	6.3	6.0	63.7	52.3	57.2
Normal XS2	7.8	6.4	6.5	6.1	60.3	49.7	55.2
Normal XS3	6.9	6.3	6.3	6.0	66.3	55.4	61.9
High XS1	11.5	7.1	7.7	6.5	28.2	29.0	31.0
High XS2	14.7	7.0	7.7	6.4	41.8	32.5	34.7
High XS3	15.8	7.0	7.6	6.4	43.5	32.8	37.9

Table 1 shows the standard deviation and midrange percentage of the original image, 11 by 11 HPF, 21 by 21 HPF, and vertical first-difference for the dark subarea (Mauna Loa volcano). The percentage of pixels with DN values at midrange are shown because these values are an indication of the amount of subtle changes present in the image and corresponding to local detail (Chavez and Bauer, 1982). For example, in a vertical first-difference image if 60 percent of the pixels are at midrange, which indicates no difference, the amount of local detail is less than in a first-difference image that contains only 30 percent of its pixels at midrange. The differences in the standard deviations of the normal-versus high-gain images are approximately the same ratios seen between the gain values used; as should be expected. The standard deviations of the HPF images of the high-gain data are increased as compared to the HPF's images of the normal gain by about 10 and 20 percent for the 11 by 11 and 21 by 21 HPFs, respectively. The increase for the first difference images is about 10 percent. Both the HPF and first-difference algorithms are designed to enhance local detail and are affected by the amount of DN changes within the neighborhood of the filter (Chavez and others, 1976; Chavez and Bauer, 1982; Chavez and Berlin, 1984). The less local detail, the more homogeneous the DN values are within a given area/window, and the more pixels that can be assigned to or near the midrange, indicating no difference between a pixel and its surrounding neighborhood. The HPF centers the output DN values at 127.5 (127 and 128) and the first difference at 127.

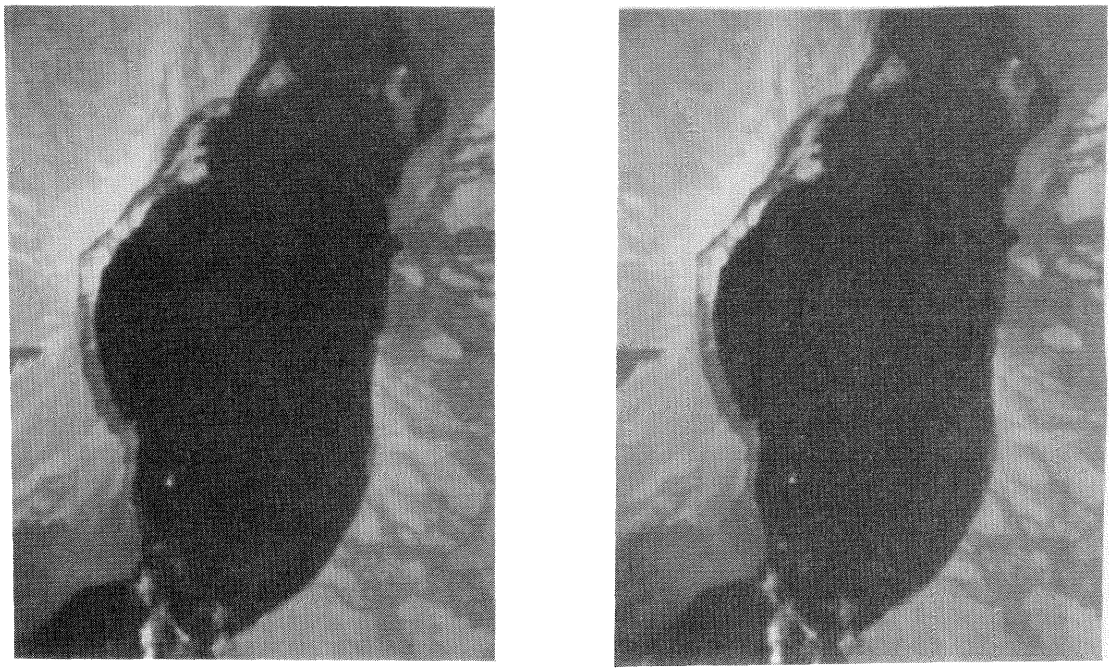
Table 1 shows that there is a dramatic decrease in the number of pixels at or near the midrange DN values for the HPF and first-difference high-gain images as compared to the normal-gain images. There are from 44 to 125 percent more pixels at midrange in the normal- versus the high-gain images, with the overall average difference equal to 70 percent. XS1 had the largest difference, but it also had more noise (vertical striping) than the other two bands. However, the average difference for bands XS2 and XS3 for all three image products is still high (57 percent). The vertical first difference, which does not see the vertical striping, has a difference of 85 percent for XS1.

In order to visually compare and evaluate the two data sets, the user must be aware of what doubling in gain will do to the data. If color composites and/or black and white prints are made using standard linear-contrast stretches on both the normal- and high-gain images, little, if any, difference will be visually detectable at typical image scales used for photointerpretation (see figures 1a and 1b). This is because the changes that occur are at the one to one-half DN level and the overall contrast of the entire image overshadows the subtle local changes.

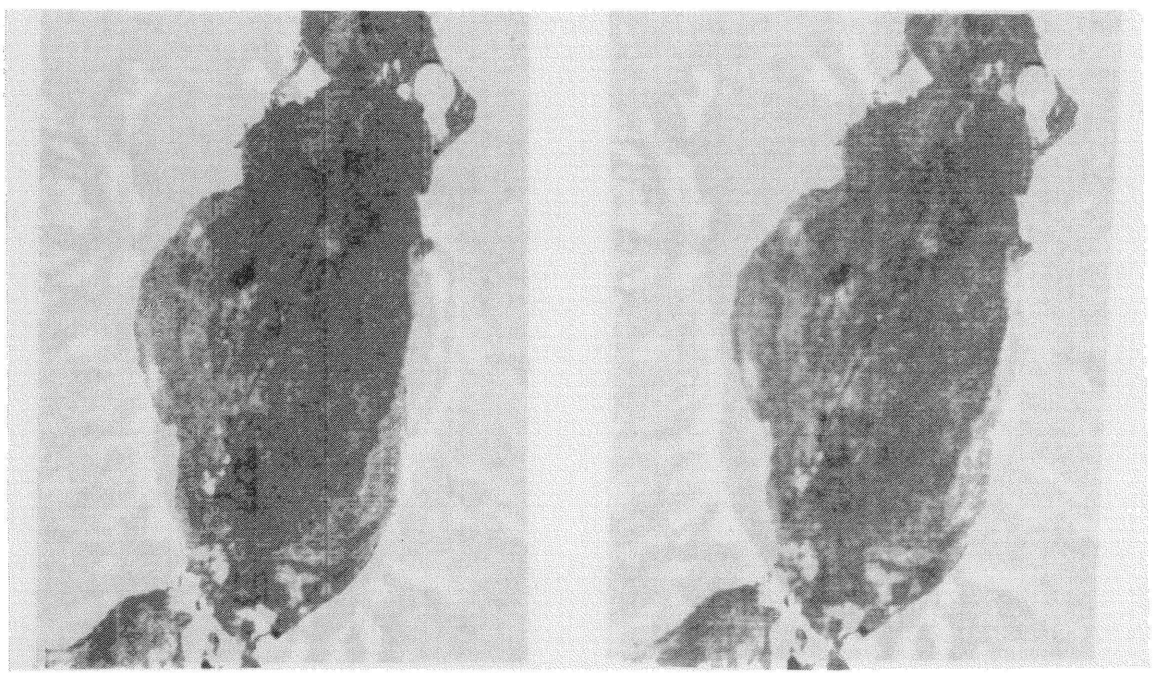
In order to see local detail where the level of DN differences is small, either very hard contrast stretches must be applied to a selected narrow DN range (figures 1c and 1d) or spatial filtering techniques that enhance local detail must be used (Chavez and Berlin, 1984). In the following examples these types of image processing algorithms were used to show the difference between the normal- and high-gain images. Color composites of the enhanced results were used in the analysis; however, only black and white prints are shown due to cost and space limitations. The results were similar in the three bands, as is shown by the statistics in table 1. As stated earlier, XS1 of the normal data set did have more vertical striping than the high-gain XS1 image, but visually the results were similar to those seen in XS2 and XS3. The differences between the normal- high-gain images are easier to see if the image products are viewed at larger scales than those typically used for photointerpretation. This can be done by either using an 8X loupe or digitally enlarging the images to allow prints to be made at larger scales than usual (for example, by a factor of seven). The digitally enlarged images were then smoothed with a 7 by 7 filter to reduce the 'blocky' appearance introduced by the digital enlargement (Chavez and others, 1984).

The visual differences seen between the normal- and high-gain data are directly related to the contouring versus non-contouring effects caused by compressing the brightness or DN range in one image relative to the other. For example, if a range of ten DN are compressed to a new range of four or five DN, which is the approximate difference between the high- and normal- gain data, quantizing or contouring effects will be seen in the compressed image at the local scale. This effect will be especially noticeable on image products generated using algorithms designed to enhance local detail, such as with high-pass filtering and first-difference algorithms. The set of images shown in figures 1-4 are products of the Mauna Loa volcano area. The inside of the crater has very dark volcanic rocks while the outside slopes have basalts that are not as dark. Figure 5 shows an example of an area with much higher reflectance values than the
Mauna Loa area.

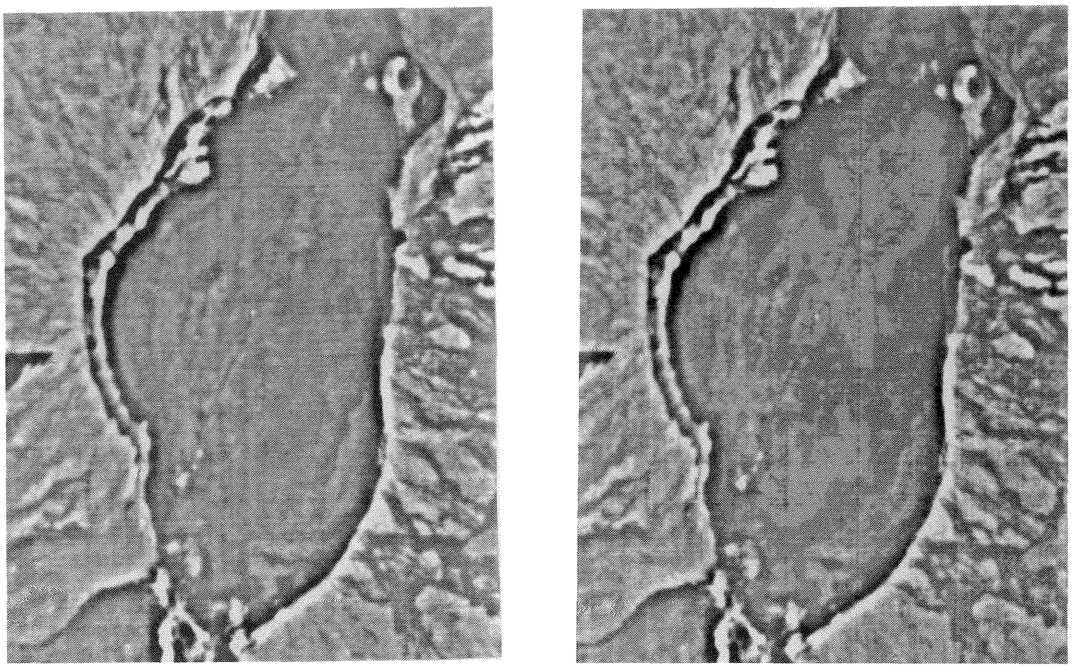
As stated earlier, figures 1a and 1b show the normal- and high-gain original XS2 images with standard linear contrast stretches and figures 1c and 1d with very hard linear contrast stretches applied. Some of the local detail present only in the high-gain image can be seen in the hard-stretched products. However, the local detail differences and the quantizing/contouring can be seen better in high-pass filtered images. Figures 2a and 2b show the results of the 11 by 11 high-pass filter and figures 3a and 3b show the results of the 21 by 21 high-pass filter. Notice that due to the quantizing effects, the trail going through the center of the crater can be seen better in the high-gain image. This results from the increased incremental DN difference or reflectance resolution in the high- gain data and not in the normal-gain data. The high-gain data have approximately twice as fine a brightness resolution due to the gain difference, so it can show the subtle contrast between the trail and the surrounding background. Keep in mind that similar results are also seen in areas with bright reflectance.



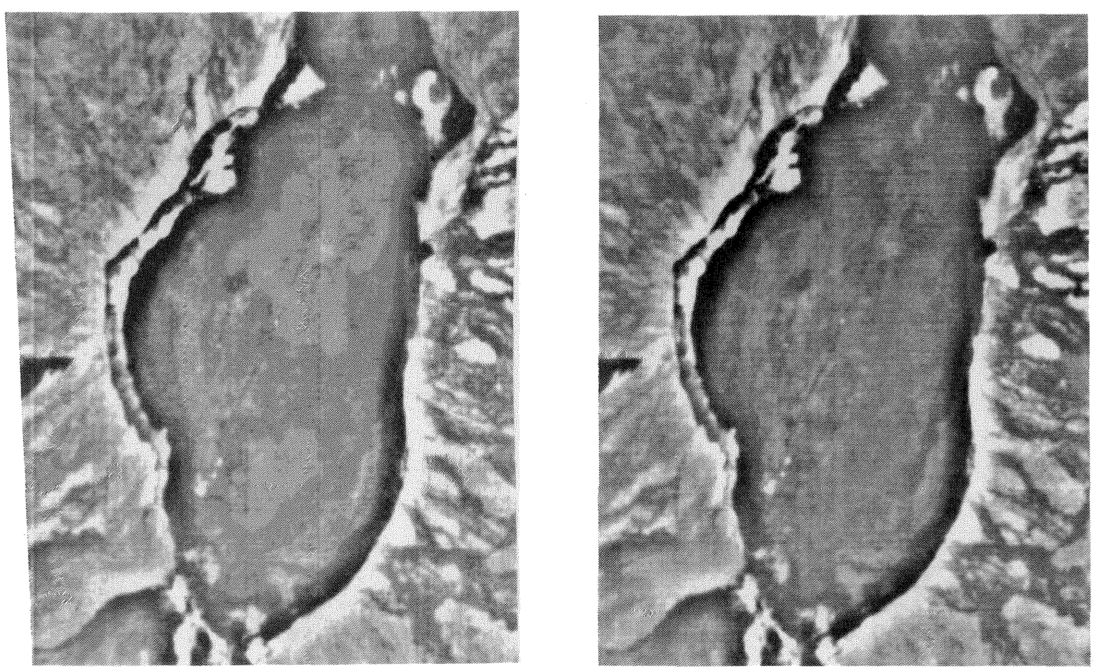
Figures 1a and 1b
Normal (left) and high (right) gain original Xs2 data, centered on the Mauna Loa volcano on the big island of Hawaii. The same percentage of saturation to 0 to 255 DN was used to keep the overall contrast of both images the same. North is approximately to the top and the distance across the crater (top–to–bottom) is about 6 km. As the standard linear contrast stretches, the overall contrast overshadows the small local DN changes.



Figures 1c and 1d
normal (left) and high (right) gain original XS2 data with very hard linear contrast stretches. The data were stretched to enhance the dark/lower region of the histogram and show detail within the crater. Note that some of the quantizing/ contouring effects can be seen in the normal–gain image; however, the high–pass filtered print show this effect more dramatically.



Figures 2a and 2b
The results of applying an 11 by 11 high-pass filter (HPF) to the normal (left) and high (right) gain XS2 images. The quantizing/contouring effects due to the smaller compressed DN range of the normal gain image (1.7 difference) can easily be seen, especially inside the Mauna Loa crater where the variation in reflectance is small.



Figures 3a and 3b
The results of applying a 21 by 21 high-pass filter (HPF) to the normal (left) and high (right) gain XS2 images. This, like the 11 by 11 results, also show the quantizing/ contouring effects.

Figures 4a and 4b are image results of the vertical first difference, which approximates the vertical first derivative, of the normal- and high-gain images. The vertical direction was selected in order to minimize the vertical striping effects on the results. The algorithm looks at DN differences that occur at the pixel level (Chavez and Bauer, 1982). Notice that the normal image (fig. 4a) has more pixels at midtone, which implies no difference, as compared to the high-gain image (fig. 4b). This agrees with the statistics shown in table 1 which indicate 55.2 percent at no difference for the normal XS2 image versus 34.7 percent for the high-gain XS2 image. This implies that the normal-gain image is less busy or more homogeneous at the local level than is the high-gain image, as expected.

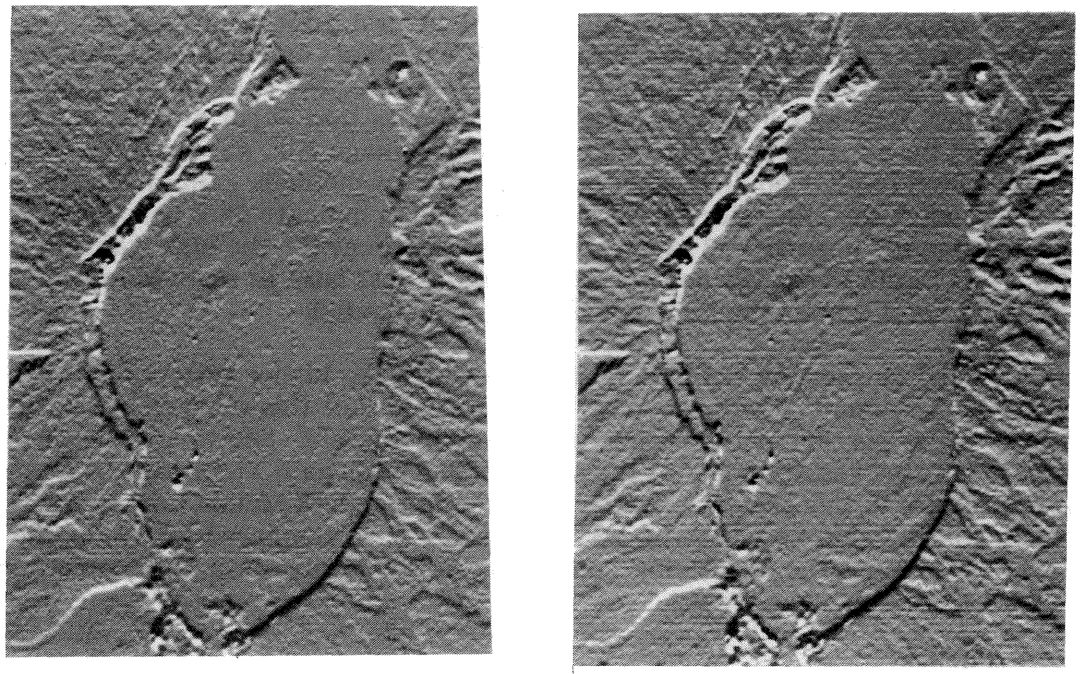
Figures 5a and 5b show an example of an area which has higher reflectance than does the dark Mauna Loa volcano area. The DN values of this subarea are in the middle to upper portion of the entire XS3 image histogram. Shown are the 11 by 11 high-pass filtered results for both the normal- and high-gain XS3 images. As can be seen the results in this area are similar to those in the dark Mauna Loa area. The difference in the gain between the XS3 images is 2.2 as compared to 1.7 for the XS2 images. This makes the quantizing/contouring in the normal data more severe as compared to the high- gain data.

CONCLUSIONS

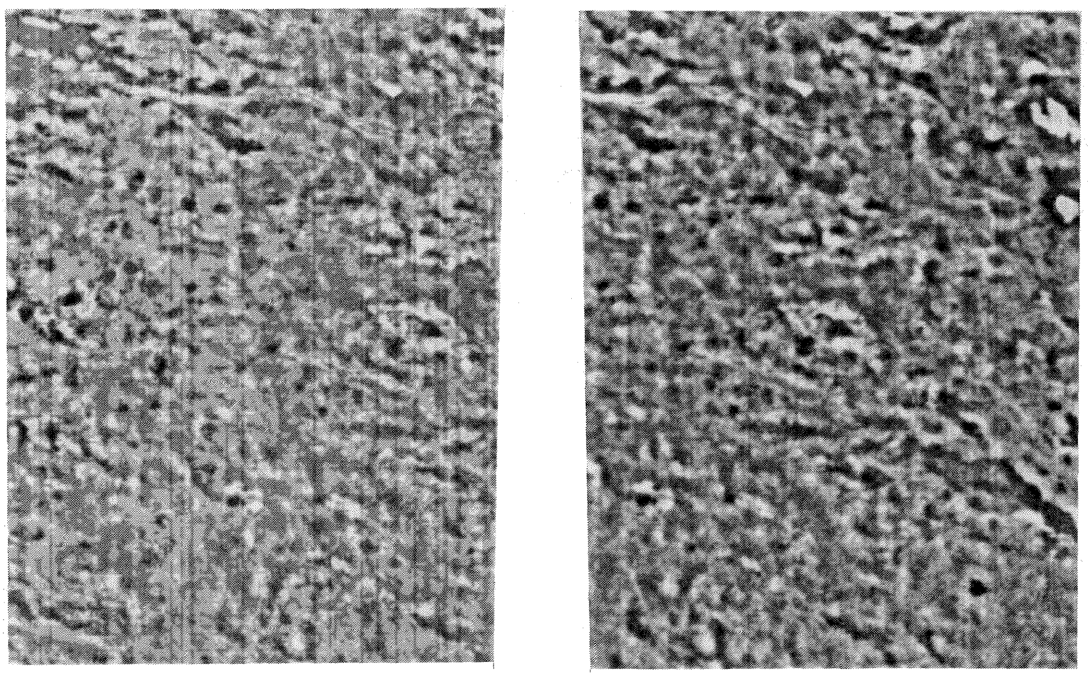
In the high-gain images all the clouds did not saturate and the maximum non-cloud reflectance in SPOT bands XS1 and XS2 was not close to saturation. In the near-infrared XS3 band the DN values of the maximum non-cloud reflectance were near 240. The pixels with these high DN values were occurring in densely1 vegetated areas that typically have a high infrared response during this time of the year. Since all the clouds did not saturate and their reflectance is relatively high in comparison to most other cover types, the results indicate that the high/maximum gain settings of SPOT can be used in many areas without causing a saturation problem. This would allow digital images to be collected with the maximum possible DN range and reflectance resolution. Extensive testing should be performed to determine what conditions would cause saturation problems. Perhaps problems would be encountered only over bright deserts during high Sun elevation, the snow-covered areas near the poles benefit from the low Sun elevation that usually exists in these regions.

Based on the results of this project, if the maximum gain settings are used over dark mountainous terrain, the local detail should be improved. There are several applications that could benefit from this improvement. For example, applications that use digital image correlation, such as image-to-image control-point identification and digital correlation for automatic stereo compilation, would benefit. Also, applications that make use of spatial filtering algorithms could benefit because of the increased local detail that would be present in the image.

The variable gain of SPOT is a new capability that has not existed in previous systems. It was advertised as a new improved capability (Courtois, 1984). However, as of mid-1988 the availability of the variable gain option to the general user community was not clear. Apparently the user can not request gain settings of his/her choice. Gain settings of low, medium, or high can be requested, but CNES will decide what this means for the given area (Rob Lees, personal commun., April 1988). The maximum gain settings (M=8) will not be used at the user's because the noise level could be unacceptable (Rob Lees, personal commun., April 1988). However, in this project the normal gain settings data had more noise/striping than did the high/maximum gain settings data. This could be due to the fact that with the maximum gain settings the detector-to-detector radiometric calibration actually works better because of the improved radiance resolution (i.e., one-half versus one DN incremental difference in the image data). For users, this has put



Figures 4a and 4b
These prints show the results of a vertical first difference, which approximates a first derivative, of the normal-(left) and high-(right) gain XS2 images. As predicted in table 1, the normal image has more homogeneous areas than the HPF results.



Figures 5a and 5b
The results of applying an 11 by 11 high-pass filter (HPF) to the normal (left) and high (right) gain XS3 images in an area brighter than the dark Mauna Loa volcano. The DN values are in the mid to upper region of the entire image histogram (excluding clouds). Notice that the quantizing/contouring effect is also present in this area. The difference in the gain between the XS3 images is 2.2 as compared to 1.7 for the XS2 images. Also, the noise/striping on all three XS bands is greater for the normal image.

SPOT close to the same category as the other systems that collect data with the same constant settings regardless of the type of area being imaged or the intended application of the data. The results obtained in this project indicate that perhaps the decision to not make the variable gain option available to the users other than in the low, medium, or high type mode should be reviewed. At a minimum, the normal gain settings should be reviewed and changed to higher settings if further testing indicates that a saturation problem will not occur. Perhaps, something like 8,8,7 during low Sun elevation seasons and 7,7,6 during high Sun elevation seasons.

What is needed in future systems (such as SPOT-3, Landsat-6, and EOS) is both a variable gain and variable offset capacapability. By including variable offset, the radiance value that is mapped to zero DN can be changed according to the minimum reflectance value that is expected, or is of interest, in the area to be imaged. This would allow the reflectance range in both dark and bright regions to be maximized using predicted gain and offset settings. If only variable gain is available bright regions will have the problem that a large percentage of the available DN range will be empty because it is 'reserved' for reflectance levels much lower than those actually present in the area of interest.

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