Improving the Quality of Satellite Image Maps by Various Processing Techniques

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Abstract

During the process of satellite image map production the scanner data undergo quite a number of processing algorithms in order to achieve geometrical rectification and radiometrical enhancement. However, some of these algorithms, e.g. resampling techniques, are connected with undesired secondary effects degrading the quality of the data. Therefore processing algorithms must be carefully applied and special enhancement techniques need to be developed. This is of special importance if data from new sensor systems are concerned. Only sophisticated processing algorithms make full use of the mapping potential of these data possible.

This paper describes various processing methods and their application to satellite image data such as MOMS, THEMATIC MAPPER and SPOT-HRV. This includes radiometrical processing, geometrical resampling with minimized degradation of lines and edges by means of pixel doubling, enhancement of particular features with statistical methods or filter techniques. The combination of SPOT panchromatic and THEMATIC MAPPER data is carried out in order to combine multispectral information and the very high resolution data to a high quality image map. The results of the applied methods are visualized and discussed critically.

1. Introduction in satellite image map production

In the course of a modern satellite image map production the data processing is done entirely by digital techniques. For this purpose a comprehensive software system has to be used, which covers all the aspects involved. Such a software system can be split up into several subsystems, each one covering a group of processing operations in a special software package. The software developed at the Technical University of Berlin follows the general outline which is sketched in figure 1. The main aspects of the approach are briefly described below.

Preprocessing: Preprocessing has a radiometrical and a geometrical aspect. The original satellite scanner data undergo at first some radiometrical preprocessing, e.g. elimination of striping effects, because these techniques in some cases require the original image geometry. The purpose of geometrical preprocessing is to eliminate the distortions caused by several system parameters, as far as these distortions are not yet corrected by the ground receiving stations delivering the data.

Geometrical mosaicking and rectification: For the production of satellite image maps usually several scenes have to be mosaicked and rectified to fit the coordinate system of the map. The parameters for this process can be determined simultaneously in a least squares adjustment for all the scenes involved. For this purpose the geometric reference system of the map has to be defined by a sufficient number of ground control points. In order to ensure geometrical continuity between the scenes, some identical image points within the overlapping sections of adjacent scenes are used as tie points. This has the advantage that less control points are needed for rectification and that the geometrical quality of the result is improved. Mosaicking and rectification itself is performed by means of transformation parameters resulting from an overall least squares adjustment. Rectification also requires resampling of the image data in the matrix format of the map sheet. In this case several algorithms are available. For practical reasons an algorithm should be selected which preserves the image information as far as possible and yields good image quality.

Radiometrical mosaicking and post processing: Due to a variety of effects the radiometric information of image data differs significantly between adjacent scenes and even within a single scene. Therefore it is the purpose of the software package for radiometrical mosaicking to convert the data of several scenes into a common radiometric system. Furthermore the resulting image data must be enhanced in order to achieve an optimum visual presentation in the final map product.

The radiometrical mosaicking procedure makes again use of the multiple information within the overlapping areas of adjacent scenes for the calculation of correction tables for each scene and each spectral band. These tables are used finally to transform the gray values of every scene involved.

After the removal of redundant information in the overlapping areas, a complete image mosaic is available with just one gray value for each pixel in each spectral band and without any edges of brightness at the border lines of adjacent scenes.

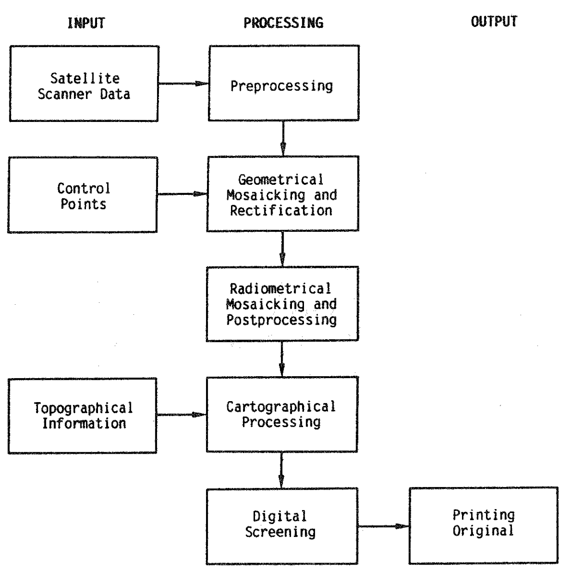

Fig. 1: System overview

Cartographical processing: The result of the geometrical and radiometrical processing is a rectified, mosaicked and enhanced set of image data for a map sheet. However, in addition to the image itself a map requires graphical elements such as lines, symbols, letters, numbers etc. representing and depicting topographical features. These elements must be superimposed to the image.

Digital screening: After integration of the cartographical elements into the image data, respectively after the generation of a seperated graphical data file, the entire set of data is ready for the generation of printing originals. For this task a large format high resolution raster plotter system should be used. By means of such systems the gray values of the image data in each spectral band can be converted to a printing screen by digital computation. Therefore the full information content of the data can also be maintained during this last step of processing.

In this entire process of satellite image map production quite a number of processing algorithms are used to improve the quality of the data. During the preprocessing for example, various methods are applied for relative radiometrical sensor calibration. Other techniques are necessary to keep the image quality during the geometrical resampling process. In the following chapters some of these methods and their application to satellite data are described as well as some techniques for data combination using satellite images from different sensors:

- image resampling by pixel doubling,
- relative calibration of detector data,
- merging of different satellite data.

2. Image resampling by pixel doubling

Any geometrical image transformation makes it necessary to resample the data, i.e. for each pixel of the output matrix a gray value has to be determined from the input matrix data. For this purpose various resampling algorithms can be used, for example: nearest neighbour, bilinear interpolation, cubic convolution, Lagrange polynomials. The first method maintains the original gray values, whereas the other methods determine the new values by calculation between the gray values of the more or less surrounding pixels. Differently resampled images show evident differences between nearest neighbour, bilinear interpolation and cubic convolution results. But even for experienced interpreters it is difficult to find differences between cubic convolution and Lagrange methods. Hence, for practical applications the Lagrange polynomials must be preferred, because this method needs less computer time than cubic convolution.

The process of resampling is always connected with some degrading of the information content of the data. It is of course desirable to keep this degrading effect as small as possible. This can nearly be achieved by the application of more sophisticated resampling algorithms. However, complex resampling algorithms also require gray value calculations - e.g. extrapolation technique - and for that reason the original data get lost. Furthermore, the use of such algorithms is connected with an increase of computer time. Therefore a compromise must be found taking into consideration the information content of the data, the visual impression of the images and the computer time requirements. The differences between the resampling algorithms are evident in regions with many man-made features, like streets, buildings etc., but in more homogeneous regions without any significant features, e.g. in desert areas, a simple algorithm is sufficient.

If resampling is performed with an artificial "higher resolution", i.e. smaller pixel size compared to the original data, good results can be obtained (KÄHLER & MILKUS (1986), COLVOCORESSES (1986) and GOSSMANN (1984) e.g.). Experiments were carried out in order to achieve further improvement. It turned out, that a simple trick, namely doubling the lines and columns in the original image matrix, combined with bilinear interpolation yields very good image quality in the resampled image. In this case the statistical probability for keeping original gray values is increased.

Thus the approach preserves the original contrast to a high degree, but at the same time smoothes the steps along edges. The edges are enhanced in a later process using special filter techniques. Figure 2 shows experimentally the results of the doubling method for an idealized target in comparison to other resampling techniques.

However, it must be pointed out, that the method requires a large amount of disk memory, which may be a limitation for practical use.

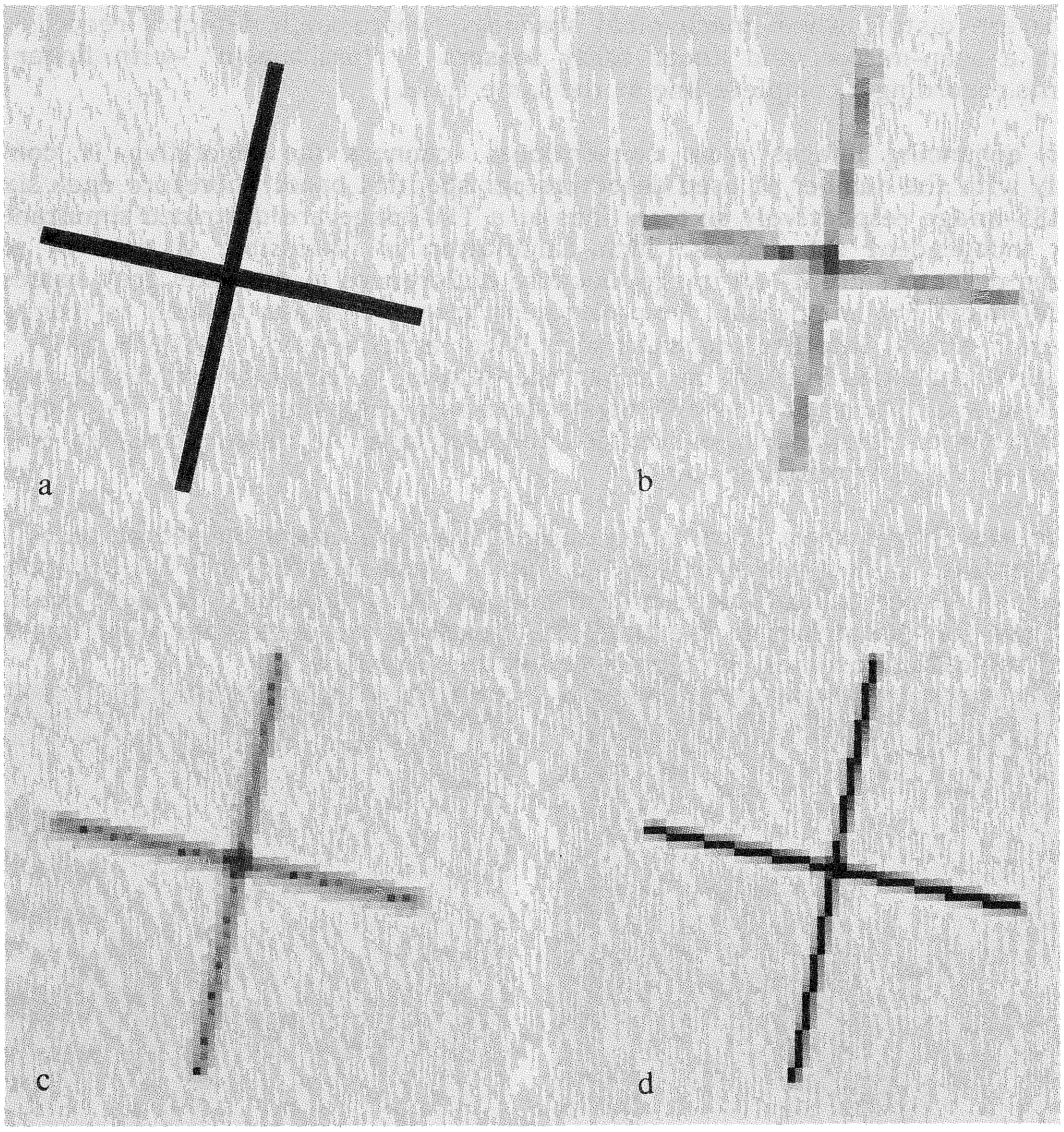

Fig. 2: Results of different resampling techniques for an ideal target:
a) original data, b) bilinear interpolation with original pixel size,
c) bilinear interpolation with smaller resampling pixel size,
d) bilinear interpolation with doubling of the original data

3. Relative calibration of detector data

Due to the system configuration of satellite scanners with six (LANDSAT-MSS), sixteen (LANDSAT-TM) or more adjacent sensors (MOMS, SPOT) for each spectral band, sensor calibration errors lead to a striped pattern within the images. These errors are regular but not constant throughout: they are dependent on time and on the intensity of radiation measured by the scanner. In order to get a homogeneous image it is necessary to find a solution which functions for each class of gray values. Therefore single detector histograms are calculated, and by defining an artificial 'median' sensor the data are converted to this detector using correction tables. The transformation is derived from integral histograms.

For this purpose the image structure - lines and columns - has to be unchanged and not resampled, because the original detector statistics is required. The image destriping technique depends mainly on the properties of the scanner systems, and it is evident that different sensors need different processing steps. In this context two main systems are distinguished: **mechanical scanners**, where each detector records a line through a scan-mirror, and **linear array sensors** - "pushbroom" -with linear CCD elements recording a complete line at the same time.

For enhancing images from conventional scanners the algorithm is combined directly with the number of used detectors per spectral band. Therefore each six lines of a MSS-image respectively sixteen lines of a TM-image are destriped simultaneously within independent sub-images. Such calculation is impossible if data of several thousand detectors create an image, because differences in the pixel gray values over a whole image line may result from different ground features as well as from sensor calibration errors. Satellite scenes of such linear array sensors - MOMS, SPOT etc. - can also be enhanced in small parts, just the data of **n** detectors simultaneously. But these image parts are not independent, because an overlapping area of **n - 1** detectors is used between neighbouring subimages for destriping; in other words, an operating sub-matrix is gliding over the scene.

Satellite images from linear array sensors may even show striped patterns in two directions (Fig. 3). In flight direction - column - such interferences are dependent for example on sensor calibration errors, in line direction variations of these errors may be reasons for the stripes in the images. Therefore the destriping algorithm has to correct the data two times, in column- and in line-direction.

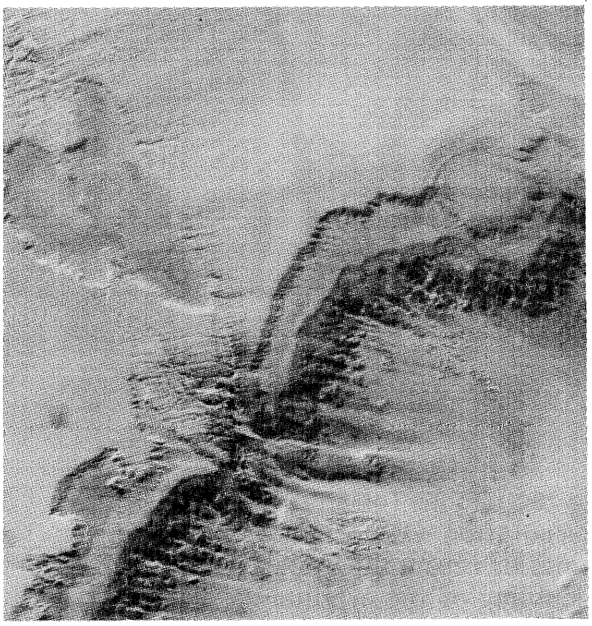

Fig.3: Striped pattern in a MOMS-satellite-image of Baris, Western Desert, Egypt, (1:100,000)

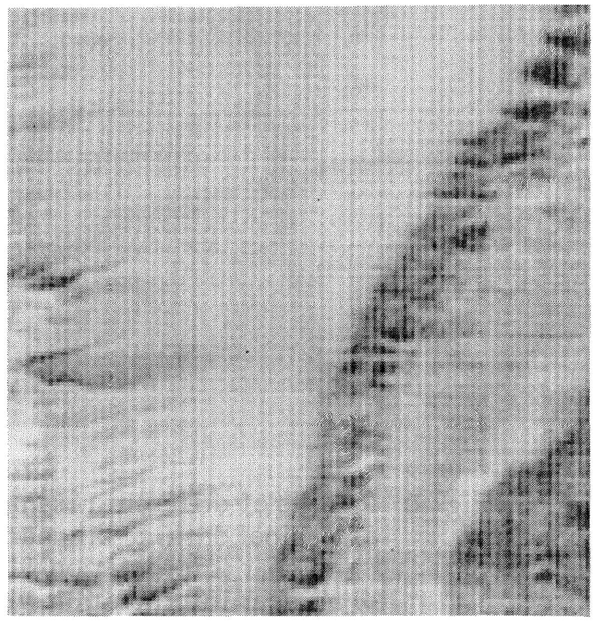

Fig.4: Inhomogeneous stripes, enlargement of the central area in figure 3, (1:20,000)

A special advantage of the statistical destriping algorithm, using integral histogram equalization, consists in its flexible applicability, especially for enhancing images of extremely poor quality. The MOMS scene in figure 3 for example has just about twenty different gray values in the original image data and shows inhomogeneities as secondary effects in the stripe's structure. The enlarged part, shown in figure 4, demonstrates such inhomogeneities in the horizontal stripes. The structure changes drastically at a vertical column, where light lines change into dark lines and so on. Similar but not so outstanding effects can be seen in SPOT-HRV-images. Enhancing such images the statistical algorithm is applied to subimages followed by an easy kind of mosaicking process to get a completely destriped result image (figure 5).

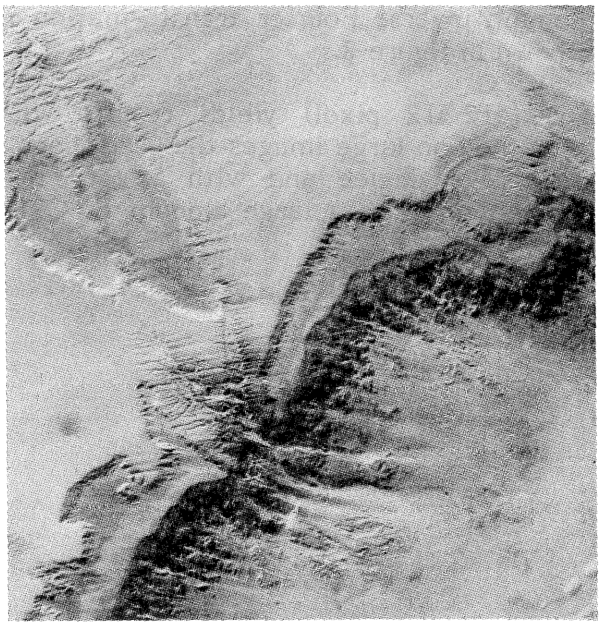

Fig.5: Result of the statistical destriping algorithm enhancing the MOMS image of figure 3

The destriping process is really time consuming, using the statistical algorithm to correct images of such low quality. This is why other also very time consuming methods become alternative possibilities, especially filter techniques in the spatial frequency domain. In this context it must generally be pointed out, that filter techniques for destriping may produce images failed in special high frequency image details. On the other hand destriping of geometrically processed data using statistical methods is very complicated and also time consuming. The next example shows preprocessed SPOT-HRV-data enhanced by filter techniques.

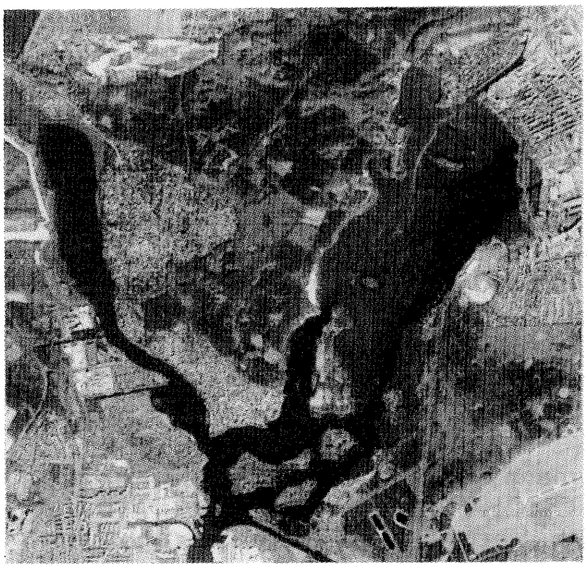

Fig.6: Striped pattern in SPOT-HRV data, Tegel Lake in West-Berlin (1:66,666)

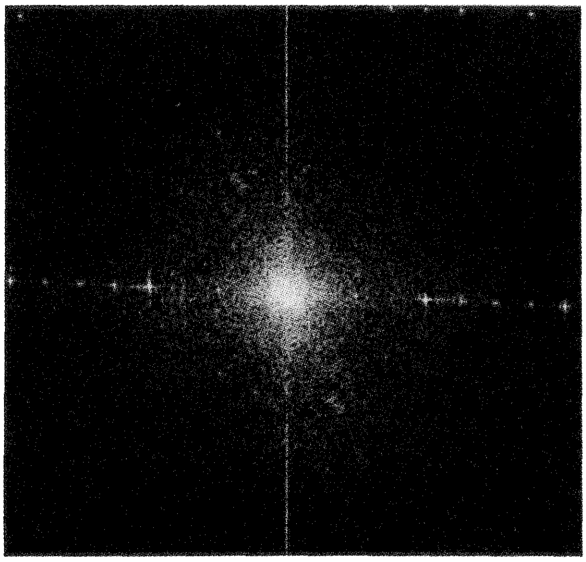

Fig.7: Power spectrum of the data in the figure beside.

The stripes occuring in SPOT-HRV data are demonstrated clearly in figure 6. The stripes in down track scan direction result from operating the two HRV instruments on board simultaneously whereas the inclination of the stripes is produced by the subsequent processing of the data to Level 1B by the receiving station.

After transformation of the image into the spatial frequency domain the power spectrum is calculated. The frequencies of stripes in diagonal direction occur distinctly as shown in figure 7. After filtering (e.g. ideal low-pass filter, pure orientation filter) in the spatial frequency domain inverse Fourier transformation is carried out. The result without any stripes is shown in figure 8.

This technique applied to small images (512·512 pixel) yields results with acceptable success. However, to perform the method on large images the user needs a sophisticated hardware with a lot of mass storage device and with a very fast processor. Otherwise this technique is not practible due to a large amount of CPU-time.

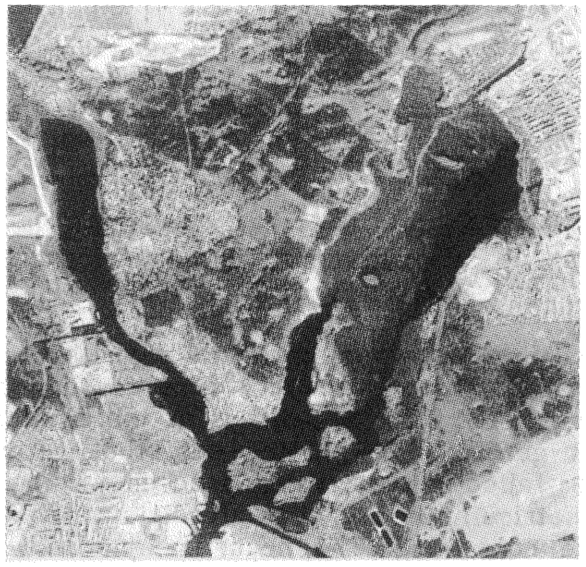

Fig.8 Destriped image from figure 6 after filtering in the spatial frequency domain

4. Combination of SPOT panchromatic and THEMATIC MAPPER data

After the launch of satellites with new remote sensing systems merging of the data from different sensors becomes more and more important. The combination of multispectral data and additional data with high geometrical resolution has been carried out in several studies in order to improve the geometrical and radiometrical quality of remote sensing data. Very different data types were used for this purpose: LANDSAT-MSS and radar data, LANDSAT-MSS and LANDSAT-RBV data, LANDSAT-TM and digitized airborne data, LANDSAT-TM and SPOT panchromatic data, SPOT multispectral and SPOT panchromatic data, etc. In particular the combination of SPOT panchromatic data and multispectral TM data, providing seven spectral bands, is of great importance for interpretation purposes and the production of satellite image maps.

Many techniques for image matching mainly for interpretation purposes are described for example in CHAVEZ (1986), CLICHE et.al. (1985), ESSADIKI (1987), HAYDN (1982), WELCH and EHLERS (1987). Methods used in this context can be summarized as follows:

- band replacement,
- principle component analysis,
- arithmetic terms,
- edge integration,
- color transformation.

Band replacement: This method cannot be expected to yield good results for the combination of SPOT and TM data. Since great emphasis is laid on a natural rendering of the earth surface, the new band to be replaced must have nearly the same wavelength as the old one. But the SPOT panchromatic band has a different characteristic from any TM band.

Principle component analysis: This technique is usually applied to compress the information of several bands into a few data sets. The combination of bands from different sensors is also possible by calculating principle components. But the application of this method for image merging can only be suggested if the bands are correlated among themselves. The results obtained by principle component analysis are suitable for interpretation purposes, but not for the preparation of satellite image maps with a natural coloration.

Arithmetic terms: In most cases arithmetic terms are applied for the combination of multisensoral data. This includes the pixelwise addition, substraction, square root after multiplication and ratioing of panchromatic data with multispectral data. Practical applications have shown that these methods could yield results with an improved quality of the image data. However, limitations must be considered in some details where the high resolution data contain rarely high frequencies. In the merged image the data with low resolution dominate at these places. This fact results in an image which has partly very good contrasts but to some extent the image seems to be smoothed.

Edge integration: Edge informations are derived from the high resolution data, e.g. by means of an high pass filter. Subsequently these informations are integrated in the data set with lower resolution, e.g. by adding. This method has similar advantages and disadvantages as the method mentioned above.

Color transformation: For the improved differentiation of image informations the transformation into another color domain can be very useful (HAYDN et.al.(1982)). For this purpose the present informations in RGB (primary colors: red, green, blue) are transformed into the IHS color domain (intensity, hue, saturation). An alteration of coloring could now be obtained by modifications of the new color components IHS. For image merging of multisensoral data the image with high resolution data is substituted for the intensity component. Subsequently the inverse transformation into the RGB color domain must be carried out.

This technique yields the best results for the combination of multisensoral data by preserving both the geometrical and spectral resolution. However, the substitution of the intensity component must be handled carefully. Data sets from different receiving dates show distinct variations of the spectral reflectances of land cover types. This results in the merged image in destroying the natural colors within the respective land uses.

The improvement of the image quality can be visualized the best in an example which contains mainly man-made features. Therefore the test area is located near the city centre of West-Berlin where urban details like buildings and streets, but also vegetation areas are present. The aim in satellite image map production in this case is to produce a map in realistic natural colors. Thus the TM bands 1, 2 and 3 are used as the fundamental color components which have to be merged with the high resolution data set. Figure 9 shows the selected area in TM band 3 which covers an area of about $5 \cdot 5\ km^2$. In Figure 10 the same area is shown in the SPOT panchromatic band, which is already processed to Level 1B by the receiving station. The TM data were taken on June 9^{th} 1984 whereas the SPOT data were acquired on March 16^{th} 1986.

Before merging the different data sets the data must undergo several processing steps. This includes various histogram modifications and destriping algorithms such as to obtain images with good contrast and natural colors. Subsequently a relative rectification connected with resampling is carried out. For this purpose the TM data are trebled in order to preserve the original contrast during the resampling process, especially in linear features (see chapter 2). The rectification with affin transformation and resampling with bilinear interpolation yields good results. Both data sets are of excellent geometric accuracy, thus affin transformation is sufficient. By that a root mean square error less than 1 pixel (10 m) could be achieved with 9 ground control points.

Fig.9: City of West-Berlin in TM-band 3, after relative rectification

Fig.10: City of West-Berlin in SPOT panchromatic band, (1:66,666)

In the next step the rectified TM data set must be transformed into the IHS color domain. In order to preserve the spectral information of TM data it can be necessary to carry out a radiometrical adjustment of the SPOT band onto the intensity component. After substitution of the intensity component the retransformation into RGB is performed. Figure 11 shows the enhanced red component (old: TM band 3) which demonstrates clearly the improvement of geometrical resolution. Additionally most of the spectral information from TM data could be preserved. Still a few histogram modifications are necessary to achieve a satellite image with optimal spectral characteristics and the geometrical resolution of SPOT panchromatic data.

Fig.11: Enhanced red component after merging TM-band 3 and SPOT-HRV from figure 9 and 10

5. Conclusions

For satellite image map production a sophisticated software system is necessary to take advantage of the full potential of all available sensors. This system must be able to process all data with the appropriate algorithm. For example each sensor system needs a special processing for correction of sensor calibration errors. With such a comprehensive software system even the production of new data sets is possible combining the advantages of different sensor systems. The merging of various satellite data is of great importance due to the launch of new remote sensing sensor systems in the near future. Therefore new techniques e.g. data cumulation (ALBERTZ and ZELIANEOS (1988)) must be introduced in order to utilize the available data optimally. This increases possibilities for the production of new maps at larger scales providing better tools for interpretation and cartographical purposes.

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