SATELLITE IMAGE MAPS – EXPERIENCES, PROBLEMS AND CHANCES

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ABSTRACT

Completely digital approaches for the production of Satellite Image Maps have been subject of research and development at the Technical University of Berlin since many years. At the Department of Photogrammetry and Cartography a software package was designed and implemented which makes full use of the flexibility of digital image processing techniques. The production line comprises: preprocessing, geometrical mosaicking and rectification, radiometrical mosaicking, merging of multisensor data, postprocessing, cartographic processing and rasterplotter printing. Mosaicking of several scenes is achieved by special techniques, based on the multiple information in the overlapping regions of adjacent scenes. In order to produce high resolution Satellite Image Maps in color, panchromatic SPOT data are merged with multispectral data from LANDSAT-TM by means of IHS color transformation. Since 1985 a number of Satellite Image Maps from various countries has been produced. Comprehensive practical experience was achieved through these activities.

The authors outline the satellite image mapping approach developed and report on practical experiences. Some related actual problems are discussed in detail, e.g. correction for relief displacements, merging of multi-sensor data, and integration of graphical elements. The system has been primarily designed to convert digital satellite image data into map formats. But also experiments making use of photographic data from the Russian camera KFA-1000 have been carried out successfully. Recent research activities concentrate on the integration of graphical elements, e.g. names, symbols, coordinates etc., into the image data. An increase in practical applications is anticipated. It is evident, that the image data prepared for the production of Satellite Image Maps can also be integrated into GIS systems and serve as a data base for thematic mapping.

KEY WORDS: Remote Sensing, Cartography, Satellite Image Maps, Mosaicking

1. INTRODUCTION

Immediately after the launch of LANDSAT-1 in summer 1972, first attempts were made to convert the MSS image data into map formats. The techniques applied were similar to the conventional (analogue) methods for the production of aerial photomaps. In the meantime a rapid development has taken place concerning the quality of satellite image data, the capacity and efficiency of digital image processing systems and graphical data processing systems as well. Furthermore, recent satellite remote sensing systems, e.g. SPOT or KFA-1000, have been designed to meet the needs of cartographic applications. Thus the potential of satellite image data for mapping purposes was considerably increased, and appropriate methods and software systems were developed. Therefore the needs of scientists and planners for actual information can be more and more satisfied, especially in countries of the Third World.

Through this development a new map type called *Satellite Image Map* became popular. It differs significantly from conventional products of cartography (Dahlberg et al., 1988). The image data provide plenty of information which is extremely useful for orientation, exploration, planning purposes, etc. This especially applies to those areas of the globe where maps at appropriate scales are not yet available, are inaccurate or out of date. But also well developed countries can substantially benefit from Satellite Image Maps, e.g. for environmental monitoring purposes and as base maps for thematic mapping. Therefore many institutions started the production of Satellite Image Maps, applying different methods and technical approaches.

2. A DIGITAL APPROACH FOR THE PRODUCTION OF SATELLITE IMAGE MAPS

Already ten years ago the Department of Photogrammetry and Cartography at the Technical University of Berlin developed a concept for the production of Satellite Image Maps which is completely based on digital image processing and takes advantage of the great flexibility of this technique. It provides software components for different types of sensor data, comprehensive radiometrical image enhancement, merging of multisensor data and various cartographic concepts. Furthermore the approach is characterized by a special mosaicking technique making use of the multiple information in the overlapping sections of adjacent scenes. The priniciples have already been described in previous papers (Albertz et al., 1987; Tauch et al., 1988, 1990) and are only briefly outlined here. The production line of this approach (Fig. 1) comprises the following main items:

The purpose of *preprocessing* is to prepare the original data for further operations. The data undergo simple histogram stretching and incorrect pixels (e.g. caused by transmitting errors) are eliminated by semi-automatic methods based on thresholding. In many cases striping effects, degrading the quality of the image data, are removed by appropriate relative calibration techniques (Kähler, 1989). If image data are disturbed by clouds, cloud shadows, industrial smoke or similar effects it can be necessary to replace part of an image by other data. This *partial substitution*. requires many processing operations and much interactive control by an operator. However, for the production of high quality Satellite Image Maps it is sometimes unavoidable.

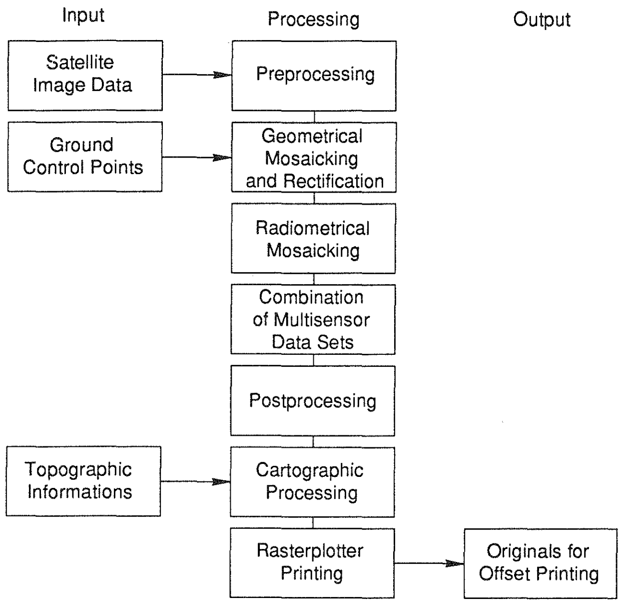

Fig. 1: The production line for Satellite Image Maps

The combination of several scenes and especially merging of multisensor data requires very precise *geometrical mosaicking and rectification*. For this purpose the well-known bi-variable polynomials based on the coordinates of some ground control points (GCP's) are appropriate. However, the best results can be achieved if all transformation parameters for a block of scenes are determinded simultaneously in a least squares adjustment. In order to reduce the number of GCP's and to improve the quality of the result it is advisable to introduce tie points (also referred to as transfer points) into the adjustment. This approch, already proposed in 1984 (Milkus, 1984), yields excellent results, and became popular in the meantime (Galtier et al., 1992; Rivereau et al., 1992).

If mountainous regions are concerned the influence of the topographical relief must be considered (Albertz et al., 1990). For this purpose the rectification based on bi-variable polynomials has been extended by approximation formulas correcting for displacements caused by heigth differences. The approach developed is based on the fact, that relief displacements only occur in the direction of the scan lines. A height difference Δh (relative to a mean terrain height) causes a displacement Δs, resulting in an incorrect position of the particular pixel (Fig. 2). With regard to rectification and mosaicking the relief displacements are of influence in two ways:

- The coordinates of the ground control points measured in the image data are incorrect. Therefore the computation of the transformation parameters is based on inaccurate data.
- The positions in the input image data computed during the resampling process are influenced by the actual terrain height.

Both effects accumulate so that the elemination of height-caused displacements becomes an important problem. If the displacements can not be tolerated and must be corrected in a particular mapping project, the availability of a Digital Elevation Model (DTM) is essential.

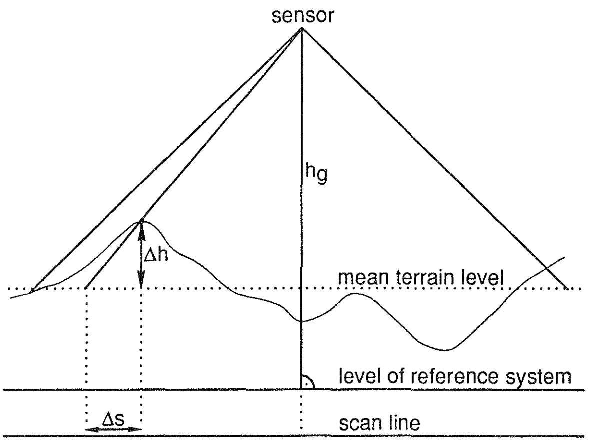

Fig. 2: Displacements Δs caused by terrain height differences Δh

For single scenes, the measured ground control point coordinates can be corrected by use of the appropriate terrain height. However, this is impossible in the case of tie points, because of the fact that usually the reference coordinates of tie points are unknown before the computation of transformation parameters. Therefore it is neccessary to develop this procedure into an iterative procedure. This is achieved in the following way. The first adjustment is carried out with uncorrected image coordinates of the tie points. Thus approximate values of the tie point coordinates will be made available. Through these coordinates a first height correction can be determined. Further iterations will then improve the previously calculated tie point coordinates until final results are achieved.

From the DTM the terrain height for each pixel can be provided for the rectification. For this procedure the following method, operating in three steps, has been developed and successfully applied:

- At first the equations for indirect rectification lead to a position in the input data for each pixel of the rectified image, without taking care of terrain height influences.
- After that the displacement correction Δs has to be added so that the correct position is determined.
- Finally the gray value for the correct image position is interpolated and transferred to the rectified image data (resampling procedure).

According to this approach the problem of rectification of satellite image data considering the terrain relief can be solved with high accuracy. Nevertheless, it should be emphasized that accurate rectification can only be achieved if precise and extensive height information in the form of a DTM is available.

After the geometrical rectification also *radiometrical mosaicking* is essential, because the radiometry of the image data differs significantly between adjacent scenes due to a variety of effects (sun elevation, atmosphere etc.). For this purpose a software package has been developed which removes brightness and contrast differences and converts the data of several scenes into one gray scale system (Kähler, 1989).

The procedure makes again use of the multiple information within the overlapping areas of adjacent scenes. The program starts with the interactive definition of the overlapping areas to be used for mosaicking. Now median integral histograms are calculated for each overlapping region. From this data base correction tables for each scene and each spectral band are derived in an iterative process. Once this is achieved the corrected single images have to be merged to one image file per spectral band. Alltogether the sophisticated software package (described comprehensively by Kähler, 1989) offers great flexibility and yields excellent results.

The combination of multisensor data is a task of great practical importance since high resolution panchromatic data from the SPOT satellite became available in 1986. It is evident that by merging multispectral data with panchromatic data of high geometrical resolution excellent results can be achieved.

A well known application is the combination of the TM system with its seven spectral bands and SPOT-HRV data with a spatial resolution of 10 m in the panchromatic mode leading to maps at a scale of 1:50,000 (e.g. Albertz et al., 1990).

In order to preserve both advantages by combining the data comprehensive investigations using the IHS color transformation (Tauch et al., 1988, Albertz et al., 1990) have been undertaken. The principle idea is to transform RGB colors into the IHS color domain. By substitution of the intensity component through high resolution panchromatic SPOT data and subsequent retransformation into the RGB color system an enhanced image is obtained. Because of different radiometric histograms it is often useful to carry out a radiometrical adjustment of the SPOT data onto the TM intensity component and to calculate the new intensity as a weighted average of both data.

Although very successful, the merging of multisensor data sometimes contains problems due to the different spectral characteristics, the geometrical resolution of the sensors and due to differences in the dates of acquisition.

Different Spectral Resolution in Multisensor Data: The high spectral resolution of the Thematic Mapper data makes it possible to distinguish various landuse classes which can not be differentiated in panchromatic SPOT data (e.g. deciduous and coniferous forest). Forest information, extracted by multispectral classification of TM data, undergoes a special contrast enhancement and is preserved after adding to the initial data again.

Different Geometrical Resolution of Multisensor Data: Due to the different geometrical resolution of multisensor data the determination of ground control points is more difficult and has to be carried out carefully. As known from experience during the production of several Satellite Image Maps the relative rectification of TM data onto SPOT data can be performed with a relative accuracy of ± 1.0-1.5 pixel (± 10-15 m) and an absolute accuracy of ± 2.0-3.0 pixel (± 20-30 m) what is less than one TM pixel.

Another effect caused by the differences in geometrical resolution is the appearence of color lines especially along edges with high contrasts. In spite of the high accuracy achieved in geometrical rectification such color lines can not be avoided, because of the differences in geometrical resolution. But in most cases they do not appear as a degradation effect.

Seasonal Effects: After merging data sets of different seasons many unnatural colors may come into being. These failures have effects on large areas and can be removed only by a lot of additional mostly interactive operations.

Land Use Changes: Often it can not be avoided to use data sets which are acquired in different years. If in the meantime the landuse of particular fields has changed this leads to unnatural colors of these areas after the combination of both data sets. These are local and irregular failures, but fortunately they occur just sporadically if the data used differ only a few years.

Tidal changes: In coastal areas it can happen, that the data to be mosaicked or merged are acquired under significantly different tidal situations. For mosaicking there might be chances to select the dividing line at places where the tidal influences are small. Otherwise there is no method known to avoid some irritating effects in the mosaic.

Usually some *postprocessing* techniques are applied after mosaicking and merging multisensor data in order to optimize the data for the particular purpose. Depending on the structure of the scene and the quality of the data as well as the particular map scale different types of edge enhancing filters can be applied in order to improve the visibility of details in the final product. Postprocessing comprises the interactive selection of the color rendition of the map to be printed.

So far all operations were carried out in the digital data files for the three colors red, green and blue, as it is common in digital image processing. However, in order to achieve a high quality image map, four colors must by applied as it is usually done in offset printing. This requires the calculation of a black color data set out of the three other data files. It will be obvious from the section below, that this operation has to be carried out before the integration of graphical elements.

The result of all the previous operations are the digital data files for each color plate. In order to generate the *originals for offset printing* these data sets must be printed on films by means of a large format high resolution raster plotter, e.g. a SCITEX or HELL system. Through this process the gray values of the image files are converted to screens, considering also the screening angles for each color.

3. CARTOGRAPHICAL DATA PROCESSING

The entirely digital approach to Satellite Image Map production also includes the digital generation, placement and combination of cartographic elements, i.e. names, symbols, coordinates etc. The integration of graphical elements into image data is a technical problem which can be handled by interactive operations if the relevant software components are available. Nevertheless, this task is also a new problem for cartographical design. Cartographers have a long experience as far as the combination of graphical elements is concerned. But so far, there is only very little experience with the integration of letters, lines, symbols, etc. into image data.

These graphical elements can obviously be integrated into the image map by simply printing it in black. However, very often the image background is dark and therefore black elements can hardly be recognized. On the other hand they can be integrated in a negative form, which is also easy to achieve. But it es evident, that similar problems occur in light areas of the image and that the graphical data can not be recognized.

In principle it is an old problem of cartography to integrate letters, symbols etc. in such a way into the background of the map, that they can easily be recognized and the map content is disturbed as less as possible. It is a quite common technique, to remove the surrounding parts of the background for this purpose. But this approach, although very successful in topographic mapping, does not yield satisfying results in the case of image maps.

Therefore a number of related experiments has been carried out. The purpose was, to find a solution for this problem by making use of the very flexible digital image processing techniques. The preliminary results of these experiments are shown in the Figures 3 to 8. It goes without saying, that the black and white reproduction can only partly transfer the impression of the colored images.

The original image data set (Fig. 3) is part of a Satellite Image Map (Laag, Somalia, 1:50,000) in the colors red, green and blue, as it is usual in digital image processing. Fig. 4 shows the graphical elements to be integrated in these image data. If these elements are simply printed in black, this results in Fig. 5; within the dark areas of the image the lines and letters are more or less invisible. The alternative, namely to integrate the graphical data in negative form by removing it from the image data, does also not produce a satisfying result. Fig. 6 shows, that the graphical elements are difficult to recognize in the light areas of the image. Furthermore, the white elements are highly dominating, and therefore the overall impression of the image is still more affected than in the previous case.

Attempts to solve the problem should obviously retain the graphical elements in black, but improve its recognizability in dark areas. This can be achieved by applying digital image processing techniques. Some tentative studies made clear, that the highest fexibility for this task is achieved after the derivation of the black color data set out of the red, green and blue data. In most cases modifications of this black channel can solve the problem, so that the basic image can remain untouched. The most successful approach, which has been tested so far, is the following:

- The graphical data are converted to a raster format which is identical to the image data.
- By means of blurring filters an unsharp mask of the graphical elements is generated.
- The unsharp mask is inverted and added to the black channel data; thus the areas of the graphical elements become lighter and this effect blurs in their direct neighbourhood.
- After that the graphical elements are added to the data of the black channel.

The result of this procedures is shown in Fig. 7. The recognizability of the graphical elements in the dark areas is substantially improved. However, the operations also work in the light areas of the image. Thus some halo effects around the elements occur at places where this is not necessary for their recognition and is degrading the image to a certain extent. In order to avoid this undesired results the operations can be modified in such a way, that only the darker parts of the image are affected. This leads to Fig. 8, showing a good recognizability of the graphical elements and a minimum of degradation of the image itself.

Further experiments will be necessary to optimize the parameters of this approach and also to find out the appropriate letter types and symbols for this task.

4. SATELLITE IMAGE MAPS FROM PHOTOGRAPHIC DATA

The concept described above was designed for the use of digital satellite image data as they are acquired by opto-mechanical or opto-electronical scanning systems. However, the software package can also be applied to digitized data from photographic cameras.

A related experiment was carried out in cooperation with the company KAZ Bildmess GmbH in Leipzig. Photographic data from the Russian camera KFA-1000 were used to generate a Satellite Image Map from the city of Leipzig and the surrounding area in the scale 1:50,000. The original photograph was scanned with a resolution of 12.5 µm by means of a HELL scanner. Because of the fact that the color film uses two layers, only two sets of digital data were really useful, the third channel was more or less noise. However, in order to make a third data file available for further processing, an 'artificial' channel was derived by modifying the red data set through an empirically defined look-up table. The result of this procedure was used as the blue channel in further operations. An additional correction for the illuminance fall-off had to be applied. Otherwise processing followed the procedures described above.

The result of the test was an image map of similar quality as it can be achieved from SPOT/TM-combinations. Some details, e.g. the texture of forest areas, were reproduced better, on the other hand photographic granularity became visible and the differentiation of colors was reduced. Alltogether the experiment was very successful.

Fig. 3: Image data of a part of the Satellite Image Map »Somalia 1: 50,000 NC-39-27-C (Laag)«

Fig. 4: Graphical elements to be integrated in the image data of Fig. 3

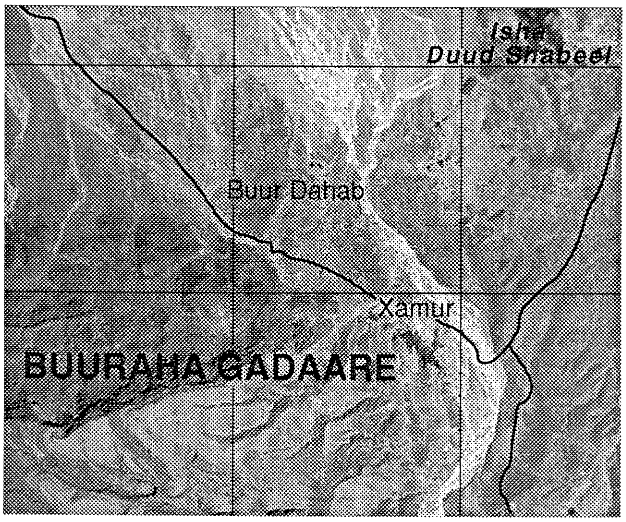

Fig. 5: Integration of the graphical elements from Fig. 4 in positive form (letters etc. printed in black)

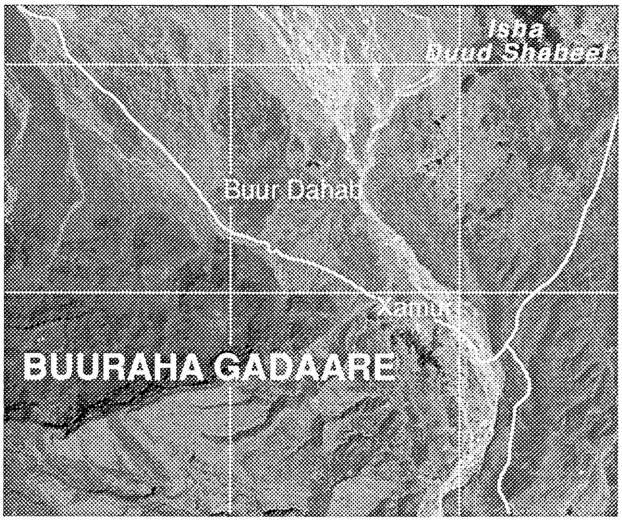

Fig. 6: Integration of the elements from Fig. 4 in negative form (letters etc. removed from the image data)

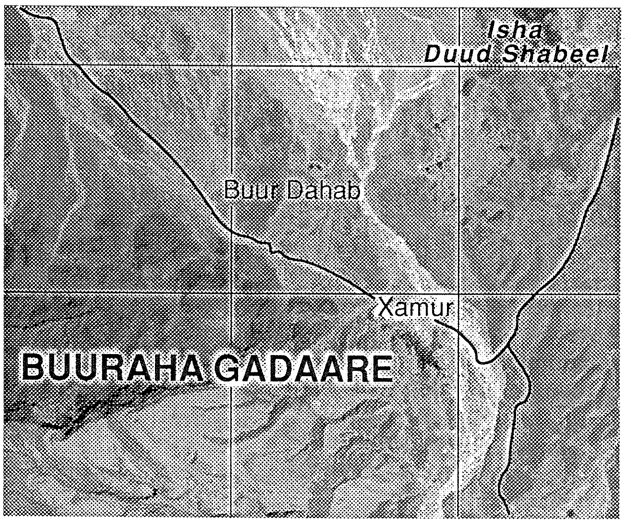

Fig. 7: Same as Fig. 5 with a brightened border around the graphical elements

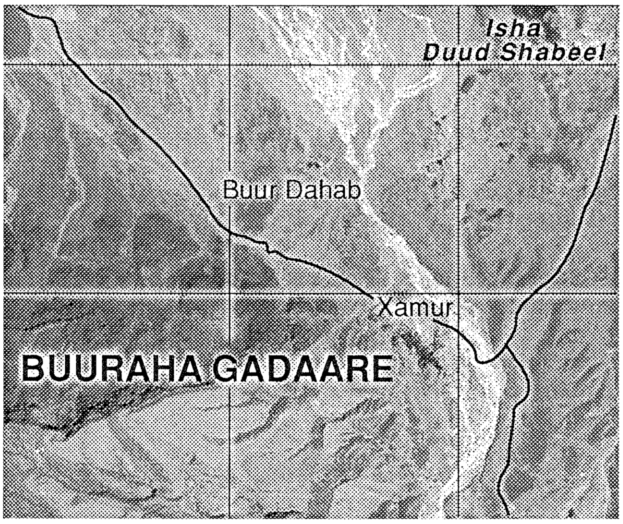

Fig. 8: Same as Fig. 7 with brightened borders around the graphical elements only in the dark areas

5. CONCLUSIONS

The availability of high quality satellite image data made it possible to develop a new map type, the *Satellite Image Map*. Effective methods have been developed to convert the original data to the form of image maps through digital image processing. These techniques offer great flexibility and ensure that the image data can be visualized in an optimal form. This is why Satellite Image Maps become more and more accepted and the production rates raised rapidly within the last years (Galtier et al., 1992; Rivereau et al., 1992).

Because of the limited resolution of the image data the production of Satellite Image Maps is restricted to certain scales. It has already been stated by Colvocoresses (1986) and it was proven by many experiments that a size of 0.3 mm of the original pixel in the final map is adequate to achieve suitable image map quality. This criterion limits the use of a particular sensor to the scales listed in Table 1.

Sensor	Resolution	Scale
LANDSAT-MSS	80 m	1:250.000
LANDSAT-TM	30 m	1:100.000
SPOT (multispectral)	20 m	1:100.000
SPOT (panchromatic)	10 m	1:50.000
MOMS-02	5 m	1:25.000

Table 1: Appropriate scales for the production of Satellite Image Maps

However, the cartographical design of Satellite Image Maps is still under development. This especially applies to the integration of graphical elements (e.g. lines, letters, cartographic symbols) and image data. The traditional experience of cartography, which deals with the combination of graphical elements, is not appropriate for this actual problem. On the other hand, digital image processing in combination with computer-assisted cartography offers great flexibility for studies and experiments in order to find adequate solutions. A series of practical studies on this task yielded encouraging results. But the optimization of the related factors will be subject to further investigations.

It is evident, that the production of Satellite Image Maps is only part of a comprehensive development. Satellite image data, mosaicked and prepared for the production of Satellite Image Maps, are also an ideal date base for many thematic mapping purposes.

Future development will be highly influenced by the availability of *Geo-Information Systems*, and satellite image data will be more and more introduced into GIS. Thus it can be anticipated, that the production of Satellite Image Maps will become a subsystem within an integrated GIS.

Furthermore, it is worth mentioning that the methods developed for mapping the Earth's surface are also of great benefit for planetary remote sensing. The camera experiments of the Russian mission 'Mars 94' are designed to acquire image data not only for interpretation but also for mapping purposes, in particular for the production of image maps (Albertz et al., 1992)

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