AN EXPERIMENT OF CARTOGRAPHY PRODUCTION AND UPDATING USING SATELLITE IMAGES

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ABSTRACT

In this work some results of an experiment of processing a panchromatic SPOT stereo-pair by using the OrthoEngine Satellite Edition software by PCI are presented. The goal is to verify the metric accuracy of the cartographic products which may be obtained. The Test area is located in some districts of Campania (Italy), which were affected by a dramatic landslide event on May 1998.
Several tests have been performed by using the two mathematical models provided by the software in order to compute a warping transformation, which are polynomial transformations and thin plate splines. The automatic DEM extraction has been carried out by applying the method of the epipolar images, which provides a level of accuracy similar to that one achievable by using the same images not rectified, because the two procedures require the same kind of parameters (i.e. internal and external orientation parameters of the images, resampling alghoritms).

RÉSUMÉ

Dans ce travail nous presentons quelques résultats d'une expérience dans la quelle on traite une SPOT stéréo-paire panchromatic en utilisant le software OrthoEngine par PCI. Le but est de vérifier l'exactitude métrique des produits cartographiques qui peuvent être obtenus. La zone d'essai est située dans quelques zones de la regione "Campania" (Italie), qui ont été affectées par un drammatique événement d'éboulement en mai 1998. Plusieurs essais ont été réalisés en utilisant les deux modèles mathématiques fournis par le logiciel afin de calculer une transformation de déformation, qui sont des transformations polynomiales et des autres qui utilisent des fonctions "spline". L'extraction automatique de DEM a été effectuée en appliquant la méthode d'images epipolar, qui fournit un niveau d'exactitude semblable à ce qui est réalisable en utilisant les mêmes images non rectifiées, parce que les deux procédures exigent le même genre de paramètres (paramètres internes et externes d'orientation des images, des alghoritms resampling).

1. INTRODUCTION

The advantage of satellite remote sensing for cartographic production and updating in respect to the traditional photogrammetric techniques consists in the short acquisition time and the possibility to map even areas where it is difficult to access and transit.
Indeed, the satellite remote sensing allows many advantages because of the synoptic character of the information and the multispectral and multitemporal vision of the data, joined to the great frequency of acquisition due to the short revisiting time of the space vehicles.
Moreover, the satellite images supply a view of the territory to specific regular cadences, almost representing an archive of the morphologic situation at the moment of the survey.
In emergency, the immediate availability of an historical series of images on the same area allows to follow the evolution of the morphology of the land and gives the possibility to carry out a rapid update of the cartography (at least to a scale of 1:25.000).
In particular, remotely sensed high resolution satellite images, with the integration of the panchromatic metric precision and the thematic informative multispectral contribution, may be used as low cost cartographic base, carrying to the identification of territorial features under risk through remotely sensed DEMs, maps of risk of fire and landslides, etc.
Moreover, the high temporal resolution would concur a particularly effective monitoring of highly dynamic phenomena, giving the possibility to provide timely interventions.
The geometric ground resolution in panchromatic mode provided by the orbiting satellites is between 6 and 10 meters; as known from literature, this level of resolution is sufficient to update cartography to a scale of 1:25000 or less. The use of such kind of data for cartographic purposes is more difficult in respect of the traditional photogrammetric ones, because of the large amount of data and the difficulty to locate the ground control points (GCP) needed to perform the orientation of the images.

The investigation of the potentialities of satellite images in terms of precision for this goal involves, for the moment, a panchromatic stereopair of SPOT images, but a study of the potentialities of higher resolution images, such as those produced from sensor MOMS-02 P (6 m in panchromatic mode) and from the sensor mounted on satellite IKONOS 2 (1 m in panchromatic mode), has already been planned.
The present work is part of a wider project developed in collaboration with the Department of the Italian Civil Protection: the last aim of such project consists in the verification of the validity of the employment of satellite images for cartographic production and updating at several scales in the national reference system. The carried out experimentation concerns fundamentally with the first phase of this research, that consists in studying and organizing the flow of the computing operations in order to frame, from the geometric point of view, the satellite images.

1.1 The software

In order to make the geometric processing of the SPOT images OrthoEngine Satellite Edition, version 6.3, has been employed.
Through the modelling of the viewing geometry, that software is able to process one or more SPOT images, carrying out the following fundamental operations: georeferencing, image orientation, automatic DEM extraction (if stereopairs are used), and geographic feature extraction (cartography).
The software implements a mathematical model based on the collinearity condition, by applying some principles of photogrammetry, orbitography, geodesy and cartography. This model reflects the physical reality of the viewing geometry as well as all the distortions produced during the image formation, as follows:

- distortions due to position, velocity and orientation of the platform;
- distortions due to orientation, integration time and field of view of the sensor;
- distortions due to earth curvature;
- distortions due to cartographic projection.

Such an integration produces some simple and straightforward equations having few unknowns, solvable by using few ground control points (minimum four for VIR) as well as tie points if more than one image is used.
By testing the modelling method using many different images of several areas and relief, it has been proved that the amount of the accuracy of the modelling is about one-third of pixel for VIR satellite images (Toutin, 1995).

2. EXPERIMENTAL TEST

The Test area is located in some districts of Campania (Italy), which were affected by a dramatic landslide event on May 1998. The experiment has been carried out by using a panchromatic, 1B processing level SPOT stereopair, acquired on August 1999, GPC acquired from a cartography to a scale of 1:50.000 by Italian geodetic official Body (Istituto Geografico Militare, IGM) and DEMs obtained by an interpolation of orographic data from cartography by IGM too.
The experiment can be resumed in the following steps:

- image georefering
- image orientation
- image orthorectification
- geographic feature extraction (cartography)
- automatic DEM extraction (if stereopairs are used).

2.1 Image georefering

Usually, the georefering operation is carried out in a two-step process:

1. transformation of pixel co-ordinates, in which each pixel in the target (georeferred) image is transformed according to the warping chosen transformation, in order to determine a sampling location in the input (uncorrected) image;
2. resampling to determine the pixel value to be filled in the georeferred image from the uncorrected image.

For the georefering of data, OrthoEngine S.E. allows to choose between two mathematical models:

- the polynomial transformations
- the Thin Plate Splines (TPS)

By applying the polynomial transformations a new geocoded image space is created, where polynomial equations fit the ground control point using least squares criteria and the interpolated pixel values will be placed during the resampling; the number of required GCP depends on the order of the polynomial (the minimum required is seven for the second order, twelve for the third one, sixteen for the fourth one and twenty-two for the fifth one). Generally, the polynomial transformations up to the first order may model rotation, translation and scaling, with the advantage of a short computation time; the polynomial transformations of higher order result in a more accurate fit close to the GCP, but they may introduce new significant errors in those parts of the image away from them.

By using the thin plate splines functions, the unknown parameters are calculated by simultaneously interpolating all the chosen GCP and the computed function have minimum curvature among control points, becoming almost planar at great distance from them; in this way, the influence of individual GCP is localized, diminishing rapidly away from it, so that it is always possible to add more GCP in an area where the transformation is not satisfactory. In using this approach, it is very important to verify the effectiveness of the transformation by acquiring an independent set of check points in number large enough to allow a thorough control (at least half the number of GCP), since in the numerical computation of the errors TPS reproduce exactly the values of the GCPs, not providing direct means of detection errors in GCP co-ordinates.
These functions are very useful in smoothly varying transformations, such as the change of co-ordinate system, but their employment in georegistering an image in rough terrain needs the acquisition of hundreds of GCPs, dramatically increasing the total cost of the approach and the computation time.
In conclusion, TPS warping is recommended for distortions that can be accurately modelled up to ten ground control points.
The GPC have been acquired from cartography to a scale of 1:50.000 by IGM. The imaged area is covered by ten cartographic elements, which have been rasterized at grey scale tones with a resolution of 300 dpi; they have been georeferenced by OrthoEngine applying a polynomial transformation of third order on twenty-three UTM grid points and a bilinear interpolation as resampling method.
The distribution of the grid points is similar for all the used maps, and it has been chosen in such a way as to avoid alignments (the only aligned points are the four grid ones corresponding to the four corners).
In performing the georeferencing operation we obtain residuals of the same order (about 0.2 meters along both X and Y axis) for all the considered maps.

2.2 Image orientation

To perform the internal orientation of the images, for the sensor HRV of the SPOT satellites a nominal focal length of 1.082 meters, a CCD size for each pixel of 0.013 x 0.013 mm^2 and a sampling interval between two consecutive lines of 0.0015 seconds are considered. The deviations from the nominal parameters of the internal orientation can be due to the following causes:

- the sampling interval may be not exactly the same during the HRV acquisition
- the real CCD size and the focal length may not be physically exact

which produce a scale change, considered in the collinearity equations.
To perform the external orientation of the images, the collinearity equations are modified to satisfy the SPOT sampling geometry as

$$\begin{aligned} \xi_i &= -c\frac{r_{11t}(X_i - X_t^C) + r_{12t}(Y_i - Y_t^C) + r_{13t}(Z_i - Z_t^C)}{r_{31t}(X_i - X_t^C) + r_{32t}(Y_i - Y_t^C) + r_{33t}(Z_i - Z_t^C)} \\ S_\eta \eta_i &= -c\frac{r_{21t}(X_i - X_t^C) + r_{22t}(Y_i - Y_t^C) + r_{23t}(Z_i - Z_t^C)}{r_{31t}(X_i - X_t^C) + r_{32t}(Y_i - Y_t^C) + r_{33t}(Z_i - Z_t^C)} \end{aligned} \tag{1}$$

where

X_i, Y_i, Z_i	ground co-ordinates of point i
$r_{11t}, \ldots, r_{33t}$	elements of the rotation matrix expressed as functions of the attitude angles ω_t, ϕ_t, κ_t at time t
X_t^c, Y_t^c, Z_t^c	orbital parameters at time t
S_η	scale factor

the six following exterior orientation parameters are expressed by second order polynomials as functions of sampling time t related to the first scan line, i.e.,

$$\begin{aligned} X_t^c &= X_0 + X_1 + X_1^2 \\ Y_t^c &= Y_0 + Y_1 + Y_1^2 \\ Z_t^c &= Z_0 + Z_1 + Z_1^2 \\ \omega_t &= \omega_0 + \omega_1 t + \omega_2 t^2 \\ \phi_t &= \phi_0 + \phi_1 t + \phi_2 t^2 \\ \kappa_t &= \kappa_0 + \kappa_1 t + \kappa_2 t^2 \end{aligned}$$

The observation equations can be obtained by linearizing the equations (1):

$$V + \dot{B}\dot{\Delta} + \ddot{B}\ddot{\Delta} = \varepsilon \qquad (2)$$

the single dot over the symbol denotes corrections to the exterior orientation parameters, while two dots are used to denote corrections to the ground co-ordinates.
The observation equations for the ground co-ordinates may be stated as

$$\ddot{V} - \ddot{\Delta} = \ddot{C} \qquad (3)$$

and those ones for the exterior orientation parameters as

$$\dot{V} - \dot{\Delta} = \dot{C} \qquad (4)$$

The combination of the (2), (3), (4), gives a complete mathematical model of the problem, i.e.

$$\begin{bmatrix} V \\ \dot{V} \\ \ddot{V} \end{bmatrix} + \begin{bmatrix} \dot{B} & \ddot{B} \\ -I & 0 \\ 0 & -I \end{bmatrix} \begin{bmatrix} \dot{\Delta} \\ \ddot{\Delta} \end{bmatrix} = \begin{bmatrix} \varepsilon \\ \dot{C} \\ \ddot{C} \end{bmatrix}$$

or

$$\overline{V} + \overline{B}\,\overline{\Delta} = \overline{C} \qquad (5)$$

The least square solution of the bundle adjustment is

$$\overline{\Delta} = \left(\overline{B}^T \overline{P}\,\overline{B}\right)^{-1} \overline{B}^T \overline{P}\,\overline{C}$$

where $\overline{P}$ is the weight matrix of the observations.

2.3 Acquisition of ground control points

The acquisition of the GCP is one of the most critical operations, because it directly influences the results of the geometric corrections; the three most important factors to be considered in this operation are the followings:

- good precision in localizing and determining the image co-ordinates in the user defined reference system;
- good spatial distribution of the points;
- number of the points.

The points have to be "small" and well recognizable, so that the choice generally falls on intersections of main roads, river bends, coastal features and so on. In respect to the dimension, in theory it should be equal to one pixel, but in practice it is very difficult to find points which are small or medium, and even in these cases their size corresponds to several pixels.
Moreover, it is very important that the distribution of the chosen points is as more uniform as possible, starting from the borders and then covering all the image.
About the number, it should surely be greater than the number strictly needed in order to make a least square adjustment; it is advisable to select at least the double of the number of points strictly needed by the transformation.
For the exterior orientation of the images we used nineteen GCP for the left image, seventeen GCP for the right one (fifteen of them are stereoscopic), and thirty-one tie points (TP).
The selection of the ground control points has been very difficult, since the images cover mountainous areas almost without buildings, where it is hard the reconnaissance of points to be identified on the map.
In the phase of selection it has been tried to reach a compromise between the necessity of identifying well distributed points on all the imaged area and the need to keep the residuals low; this compromise has led to leave uncovered the upper right part of the images.
The amount of the residuals on the selected points in both the images is less than one pixel (10 meters).

2.4 Images orthorectification and geographic feature extraction

In order to carry out the orthorectification, an area of approximately 13 x 13 Km (the mountain of Sarno struck by the landslides) has been selected.
The digital elevation model over this area has been obtained from the orographic data by the IGM, consisting of points known in height and contour lines from the cartography to a scale of 1:25.000 with equidistance of 25 meters, interpolated by applying the finite-difference method.
The orthorectified image has been exported from the PIX format by PCI to the TIF format, in order to make possible its insertion in a CAD software and to carry out a cartographic plotting.

Since the TIF format do not preserve the information about co-ordinates of the points related to the reference system, the image has been inserted in AutoCAD 14 by using the co-ordinates of the lower left angle measured on the monitor and applying an opportune scale factor, calculated on the base of the number of pixel and lines of the image and the dimension of the pixel (10 meters).

In figure 1 the overlap of the carried out plotting and the orthorectified image is shown, restricted to the following features: roads, river, landslides and urban centres. The step size of the traced grid is 2 Km. Then, the extracted geographical features has been overlapped to the maps to a scale of 1:50.000 by IGM in order to carry out a first visual evaluation of the result (figure 2).

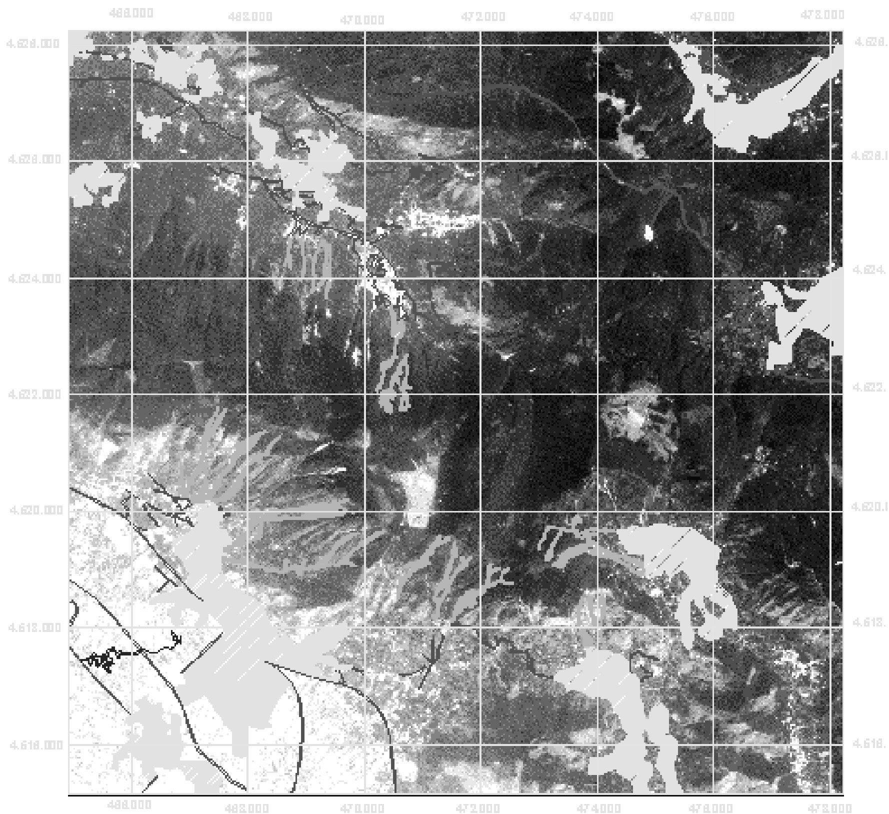

Figure 1. Cartographic restitution overlapped to the orthorectified image

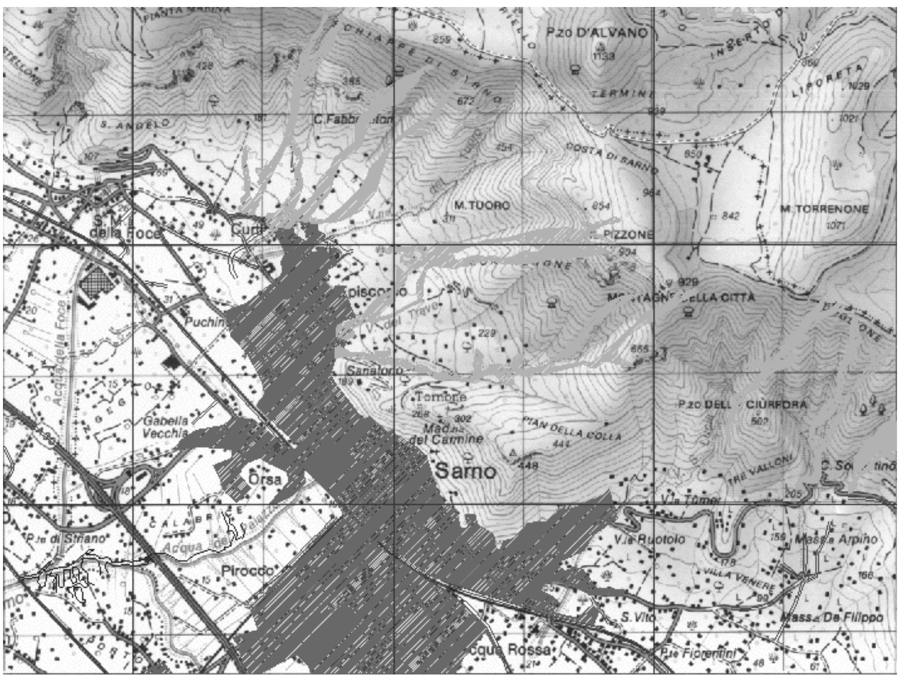

Figure 2. Overlay of the geographical features extracted from orthorectified image on the map 1:50.000

2.5 Automatic DEM extraction

The application of image correlation techniques allows to automatically extract the three-dimensional variations for the ground features from stereopair of remotely sensed images. The image matching is performed pixel-by- pixel in order to locate the best matching for conjugate point pairs by assessing template similarity; once the co-ordinates for conjugate point pairs are determined, the ground co-ordinates can be calculated by space intersection provided from the knowledge of the orientation parameters.
The epipolar method allows to carry out a mono-dimensional matching on the original images, avoiding the resampling operation when only few points have to be determined.
It is straightforward procedure to generate epipolar images for digitized aerial photograms, since the photogram has a real point as perspective centre and the epipolar images may be generated by directly applying the co-planarity condition.
It has been proved (Otto, 1988) that it is not possible to directly construct epipolar geometry for a SPOT stereopairs without a priori knowledge of the terrain morphology, because of the push-broom scanning characteristics which make co-planarity condition indeterminate.
Several algorithms for the generation of epipolar stereomates for SPOT images have been developed. The top-down approach (Ò Neill & Dowman, 1988) is based on the ray-tracing, in order to locate their intersection. The major advantage of this approach is that it may be applied to various remotely sensed images, such as SPOT and Landsat.
The disadvantages can be resumed as follows:

- the iterative calculation for locating the intersection point of the tracing rays and the canopy surface may cause the computation to be heavy;
- in resampling, the value of the nearest neighbouring points is searched in the field of real numbers and this leads to make heavy of the calculation of the grey value of the interpolated pixel.

The bottom-up approach (L.C. Chen & J.Y. Rau, 1993) has been developed in order to reduce those disadvantages for SPOT data processing. It consists in the generation of epipolar stereopair on the support of a rough DEM in order to generate a new DEM by means of least square template matching, spatial intersection and interpolation of the pixel height. The new DEM is then used as input and the procedure is repeated again and again, until the disparities between the stereomate images are sufficiently small: in this way, the final output images are also orthorectified.
One test of automatic DEM extraction has been carried out on the images oriented as described above. Orthoengine generates the epipolar images on the base of the GCP heights. From the extracted and georeferred DEM it has been possible to extract a regular grid, used to interpolate the contour lines: the imposed grid step is 10 meters. Figure 3 shows the overlay of the areas (pink in figure) where the interpolation has been succeeded on the left image; this is the result of the test carried out on the whole area covered by the images: the matching succeeded only on the 18% of the total area. The differences between the given heights and the computed ones for the fifteen selected stereoscopic GCPs vary between +1053 m to -1769 m, with an average of -523 m and a r.m.s of 751 m.
It may be said that the digital matching has failed.

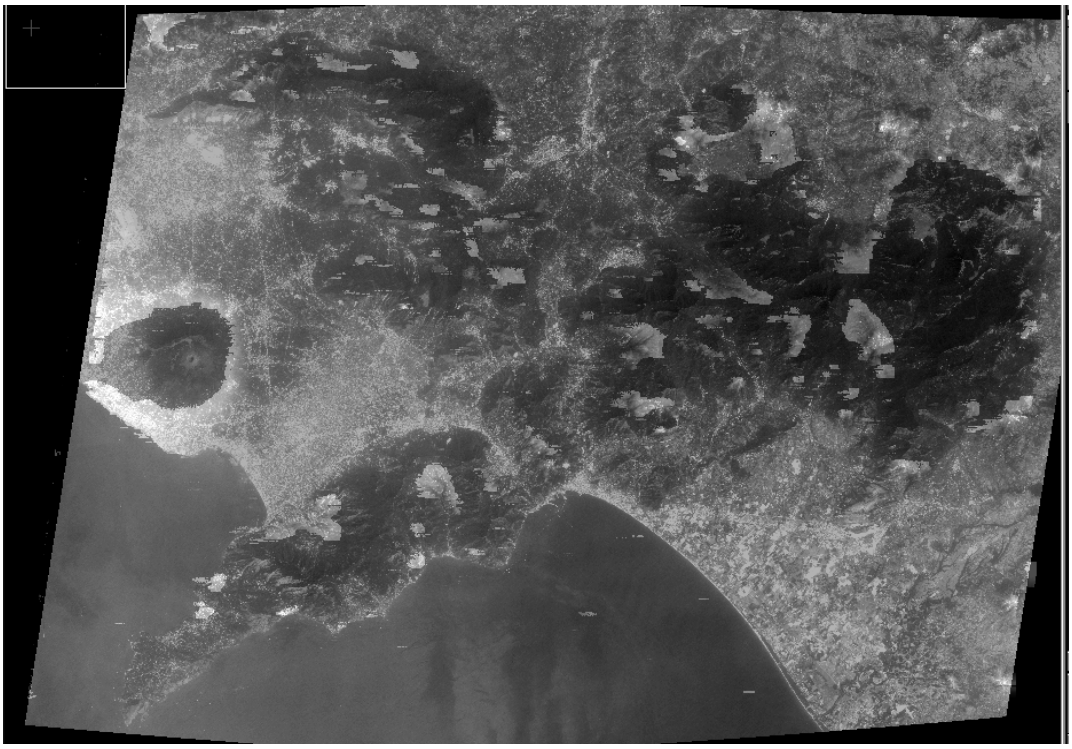

Figure 3. Overlay of the areas where the interpolation has been carried out on the left image

3. CONCLUSIONS

The described experiment is only a first approach to the problems regarding the extraction of metric information from satellite images.
The used SPOT images shows very dark areas, some of them rather confused because of clouds, which make very difficult the identification of remarkable ground features. Moreover, the viewed areas are very rough, showing complex morphological and geological characteristics.
The rapid changes from areas with low reflectance (very dark) to very bright areas generate sharp contrasts, which cause two main problems. The first one involves the operation of locating the best ground control points on the image; the second difficulty regards the sharp light contrasts, which create problems in the digital correlation techniques.
About the obtained results in these first tests, they are not good, especially in respect to the automatic DEM extraction. Our intention is to carry out more tests and to compare the cartography obtained from orthorectified images and the official one from the metric point of view.

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