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Increasing Efficiency Territory Technospheric Safety Management Based on Improving of Earth's Surface Satellite Images

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Abstract: The researchers present the results of the development and application of a method and algorithms for image restoration of the Earth's surface high resolution satellite images. This method significantly increases the visual characteristics (such as (sharpness, clarity, contrast)) of the satellite images quality which expands the range of their use in technospheric safety problems solutions, including monitoring, forecasting and decision support, along with increasing the effectiveness of the management process. The developed software implementation allows to update the practical implementation of the developed methods and algorithms.

Key words: Digital space image, the spatial-frequency range, point spread function, the generalized graded-index operator, comparing functionality

INTRODUCTION

Using of space means of Remote Sensing (RS) not only enables effective monitoring of the environment and the acquisition of new knowledge about the Earth. Today, optical range satellite images are the most important means of information support of forecasting and management in the field of territories technospheric safety (Karini *et al*., 1999; Ivashchuk *et al*., 2014a; Kussul *et al*., 2010; Ivashchuk *et al*., 2014b; Dubina *et al*., 2011).

At the same time, improving the quality of RS data which determines the degree of their reliability is most important task and requires improved methods of forming and processing of satellite images. Interpretation of satellite images, in connection with the existing frequency-noise distortions introduced by the atmosphere (especially its aerosol component) by the optical system, by the image receiver accompanied with significant problems, associated with the suppression of high-frequency components in the images (Robert *et al*., 2006; Breton *et al*., 2001; Selivanov, 2008). This leads to deterioration of quality visual characteristics of their quality, such as sharpness, clarity and contrast.

Improving satellite images parameters would be possible by making a CCD with a large number of photodetecting elements and based on them new optoelectronic devices. However, practically today such approach can't be implemented because of existing technological problems. Thus, the main areas of image processing facilities, located on the surface of the Earth, satellite images are digital techniques (Shovengerdt, 2010; Jacobsen, 2010; Park *et al*., 2003; Rashchupkin, 2008). The most famous method was the regularization method of Tikhonov (1966) recovery tasks, which, however, does not allow to recover the high frequency components and obtain output image with sufficient sharpness (Ostrikov, 2012; Sizikov, 2001).

Thus, the problem of sustainable recovery high resolution satellite images obtained in the optical range with increasing image sharpness is extremely relevant today.

MATERIALS AND METHODS

The aim of research conducted by the researchers was increasing the efficiency of information management software solutions in the field of technospheric safety, using the methods of recovery of satellite images of the Earth surface with the improvement of their acutance. To achieve this goal the following tasks are solved:

- Develop a method for the Earth's surface image reconstruction based on the modification of Tikhonov operator
- Development of algorithms for determining the reduce operator parameters
- Software implementation of algorithms for Earth's surface image reconstruction, carrying out computational experiment and the formation of practical recommendations for the application of this method

Methods of the theory of systems analysis, theory of inverse problems, Fourier analysis, optimization techniques and digital signal processing, computational experiments are used.

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RESULTS AND DISCUSSION

Main part: Mathematical model of the image is known Fredholm integral equation (Bates and Mac-Donnel, 1989):

$$u(x,y)=\int_{-\infty}^{\infty}\int h(x-t,y-\tau)f(t,\tau)dtd\tau+v(x,y) \tag{1}$$

Where:

(x, y) = Coordinates of the point (pixel) on the recorded image
$u(x, y); f(t, \tau)$ = The intensity of the reflections of the Earth's surface
$h(x\text{-}t, y\text{-}\tau)$ = The so-called Point Spread Function (PSF) which is the main characteristic that describes the structure of the object optical transmission system with a smoothing effect
$v(x, y)$ = The impact of external noise (interference)

To restore the image (i.e., the compensation steps PSF on the pictures) inverse ill-posed problem is solved: the calculation f of the data u. It was seen by many scientists as a result of the study which appeared quite a lot of methods and algorithms for regularizing the recovery. The most commonly used Tikhonov (1966), recovery operator which has the form (Ostrikov, 2012; Sizikov, 2001):

$$\hat{f}(t,\tau)=\frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int\frac{H^*(\omega_x,\omega_y)U(\omega_x,\omega_y)}{\left|H(\omega_x,\omega_y)\right|^2+\rho(\omega_x^2+\omega_y^2)^{1/2}} \tag{2}$$

$$e^{j\omega_x t}e^{j\omega_y\tau}d\omega_x d\omega_y$$

Where:

$U(\omega_x, \omega_y)$ = Spectrum of the detected image
ρ = Regularization parameter
ω = $2\pi v$
v = Spatial frequency
j = $(-1)^{1/2}$
$H(\omega_1, \omega_2)$ = Frequency-contrast characteristic (MTF) of the system (the asterisk denotes complex conjugation)

Defined as:

$$H(\omega_x,\omega_y)=\int_{-\infty}^{\infty}\int h(x,y)e^{-j\omega_x x}e^{-j\omega_y y}dxdy \tag{3}$$

Since, sufficiently rapid decay of the spectrum of the PSF in the high frequency (and the corresponding decline MTF) suppressing or complete destruction in this spectral band of small details on the generated image is occured. This in particular, does not allow to achieve a sufficient sharpness of the image. Existing recovery methods, including Tikhonov Method cannot solve this problem.

One of the most effective approaches to solving the problem of amplification of high-frequency component is the use of numerical differentiation. However, its using often leads to an excessively high level of high-frequency component in the derivative of the recorded image (overopacification).

In order to solve the problems identified by the researchers method of recovery of satellite images of the Earth surface, based on the modification of regularization method was developed and researched. At the same time, this method allows to increase the contribution of the high-frequency component with a simultaneous solution of overopacification problem.

In order to compensate for decline (correction) of MTF and the corresponding acutance increasing, additive representation of the restored image with differentiation is invited in this research:

$$S_I(x,y)=S_R(x,y)+ap(S(x,y)) \tag{4}$$

Where:

S_R = Formed image
S_I = Reconstructing image
$a>0$ = Coefficient

To construct the additive $p(S(x, y))$ which allow to align frequency components contribution, we use non-integer order differentiation operation $D^\alpha(0\leq\alpha,\ \beta\leq1)$, determines for admitting Fourier representations of functions in the form of:

$$D_x^\alpha S(x,y)=\int_\Omega(j\omega_x)^\alpha F_S(\omega_x,\omega_y)e^{j\omega_x x}d\omega_x \tag{5}$$

$$D_y^\beta S(x,y)=\int_\Omega(j\omega_y)^\beta F_S(\omega_x,\omega_y)e^{j\omega_y y}d\omega_y \tag{6}$$

where, $F_S(\omega_x, \omega_y)$ Fourier transform. In Eq. 5 and 6, the representation:

$$(j\omega)^\alpha=|\omega|^\alpha(\cos(\frac{\pi\alpha}{2})+j\operatorname{sign}(\omega)\sin(\frac{\pi\alpha}{2})) \tag{7}$$

where sign signum function. Formed additive p is essentially assessment of pseudo-gradient $grad_{\alpha\beta}$ $(D_x^\alpha S(x, y), D_y^\beta S(x, y))$:

$$p(S(x,y))=grad_{\alpha\beta}((D_x^\alpha S)^2+(D_y^\beta S)^2)^{1/2} \tag{8}$$

For effective implementation of this approach, the problem of choosing the parameters a and α must be solved.

Note the properties of the optimal (quasi-rectangular cross-sectional plane) MTF at restoration and image sharpening: all MTF are the same at low and mid-range portion and differ only in the high frequency; all MTF corresponding insufficient sharpening fit in limiting the optimal MTF; MTF with underlined the higher modes or with overopacification majorize all MTF. Thus, we define the following terms of the choice of the parameters a and α: maximizing the functional and the volume under MTF surface envelope:

$$\sum_{i,j}^{N,M} H(\omega_i, \omega_j)\delta\omega_i\delta\omega_j = \sum_{i,j}^{N,M} F(S_R)/F(S_I)\delta\omega_i \qquad (9)$$
$$\delta\omega_j = R_1 = \max$$

Where:

N,M = Size (in samples) of task spectral windows

$\delta\omega_i$, $\delta\omega_j$ = Frequency increment values

i and j = Numbers discrete samples on the axes ω_x, ω_y

Surface envelope quasismooth of the MTF and its parallel to the coordinate plane that corresponds to the calculation of the average value:

$$\overline{\mathrm{grad}_{\alpha\beta}}\, H(\omega_i, \omega_j) = R_2 = \min,\ \ \omega<\omega_2 \qquad (10)$$

Ensuring a MTF envelope steady decline, since some modeminimizing differences ω_B-ω_2(ω_B the highest frequency of the satellite):

$$\mathrm{grad}_{\alpha\beta} H(\omega_i, \omega_j) = R_3 < 0,\ \omega > \omega_2; \qquad (11)$$
$$\omega_? - \omega_2 = R_4 = \min$$

From Eq. 9 and 10 a_1 and α_1; a Eq. 11 are found and Eq. 11 is used to correct them or ignored when setting the value of an a priori defined mode ω_2. In accordance with the above let write Tikhonov filter as:

$$F(S_I) = H^*(\omega_i, \omega_j)F(S_I) / (|H(\omega_i, \omega_j)|^2 + \rho(\omega_i{}^2, \omega_j{}^2)^{1/2}) = H_\mu^{-1}F(S_R) \qquad (12)$$

Let, $H_0 = H(\omega_i, \omega_j)$ with $a = a_1$ and $\alpha = \alpha_1$. In this case, you can set the task of determining the parameter ε, introduced to correct kernel reducing operator by minimizing the residual R_5 (values of the functional comparison):

$$\sum_{i,j}^{N,M} \left| \begin{matrix} H_0(\omega_i, \omega_j) - (H^*(\omega_i, \omega_j) / \\ (|H(\omega_i, \omega_j)|^2 + \rho(\omega_i{}^2, \omega_j{}^2)^{1/2}) + \varepsilon)^{-1} \end{matrix} \right|^2 = R_5^2 = \min \qquad (13)$$

the expression in Eq. 13, we find as $F(S_R)/F(S_I)$ tract MTF, during reduction of the image with ratio Eq. 12. If the additive correction $\varepsilon = \nu(\omega_i, \omega_j)$, it negotiates these two MTF with higher accuracy. Rewrite regularized Eq. 13 in the form:

$$\left| \begin{matrix} H_0(\omega_i, \omega_j) - (H^*(\omega_i, \omega_j)/(|H(\omega_i, \omega_j)|^2 + \\ \rho(\omega_i{}^2, \omega_j{}^2)^{1/2}) + \nu(\omega_i, \omega_j))^{-1} \end{matrix} \right|^2 = R_6^2 = \min \qquad (14)$$

It follows:

$$\nu(\omega_i, \omega_j) = (H_0(\omega_i, \omega_j) + |R_6^2|)^{-1} - H^*(\omega_i^2, \omega_i^2) / (|H(\omega_i, \omega_j)|^2 + \rho(\omega_i{}^2, \omega_j{}^2)^{1/2}) \qquad (15)$$

where, R_6 plays a role similar to the regularization parameter. Considering that in its definition of MTF has no zeros, this parameter can be set = 0. As a result, we obtain the following relation for the image reconstruction based on the modification of the Tikhonov operator:

$$\begin{aligned} F(S_I) &= F(S_R)(H^*(\omega_i, \omega_j) / (|H(\omega_i, \omega_j)|^2 + \rho(\omega_i{}^2, \omega_j{}^2)^{1/2}) + \nu(\omega_i, \omega_j)) \\ &= F(S_R)(H_\mu^{-1} + \nu) \end{aligned} \qquad (16)$$

i.e.,

$$\begin{aligned} F(S_I) &= F(S_R)(H_0(\omega_i, \omega_j) + R_6)^{-1} \\ &= F(S_R)(H_0(\omega_i, \omega_j))^{-1}_{|R_6=0|} \end{aligned} \qquad (17)$$

where, $(H_0(\omega_i, \omega_j))^{-1}_{|R_6=0|}$ spectral representation of the recovery operator. For the implementation of the recovery process with different levels of sharpness, we introduce an iterative procedure using the parameter (lambda). The ratio of Eq. 16 in the form:

$$H_{\lambda\mu}^{-1} = H_\mu^{-1} + \lambda\nu, 0 < \lambda \le 1 \qquad (18)$$

When (lambda) = 1, the problem degenerates into image filtering according to Eq. 16. If (lambda)>1, there is excessive strengthening of the higher modes when filtering. Next, using the notation $Y = H_{\lambda\mu} = H_\mu/(1+\lambda\nu H_\mu)$, we implement an iterative process by the method of the geometric progression. For S_I iterative representation of the recovery integral operator (presentation of Van Cittert):

$$S_I^{(0)} = S_R;\ S_I^{(n)} = S_R + F^{-1}(1 - Y)^{**}S_I^{(n-1)} \qquad (19)$$

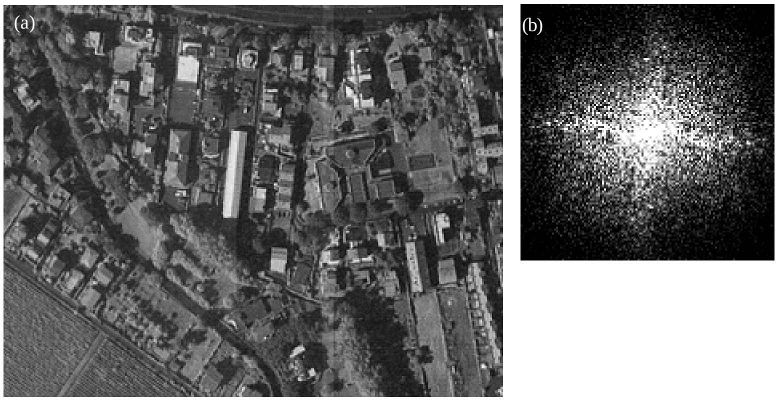

Fig. 1: Initial fragment of the DSI and its PSP

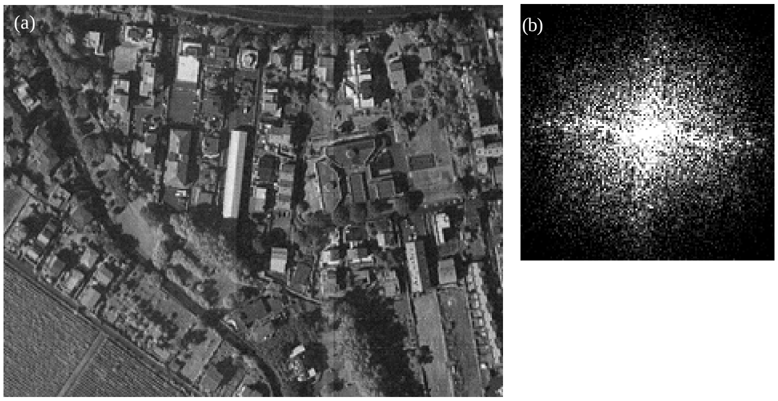

Fig.2: The result of the convolution 3×3 pixels DSI with a uniform PSF

Where:

F^{-1} = Inverse Fourier transform

$**$ = Symbol of the convolution operation

$$Y^{-1} = (1-(1-Y))^{-1} = \sum_{p=0}^{\infty}(1-Y)^{p}$$

End of iterative procedures determined by specifying, the required absolute error. For images in the palette with 24 color depth and dimension of 1024×1024 eroris 10-7-10-8 of the maximum brightness (the last 25th digit of the code panel) and requires 5-6 iterations.

Using the above method allows to realize the image recovery process with PSF smoothing action and with the evaluation of reducing operator parameters which prevents effect of overopacification.

Figure 1-4 show the results of the processing of the Digital Space Image (DSI) fragment with section of the industrial area of the city with the use of this method (Fig. 1) and their spatial-frequency Spectrum (PSP) (Fig. 2).

Fragments of the DSI used in the figures obtained from the satellite "Resurs DK". The calculated optimal values of a = 0, 1 and α = 0.15. In addition, the chapter held an adaptation of the algorithm for image restoration in the presence of spurious bands (Fig. 5).

For practical implementation of algorithms for image reconstruction based on the Earth's surface modification Tikhonov operator a prototype of a software implementation is developed as well as a comparative analysis of the proposed method with the existing methods of recovery. Implementation of the software prototype was carried out using the C # language. For the numerical evaluation of image quality differetial (R) and Spectral (S) criteria are used:

$$R = \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}(f_{mn}-f_{m+1,n})^2}{2MN-M-N} + \frac{\sum_{m=1}^{M}\sum_{n=1}^{N}(f_{mn}-f_{m,n+1})^2}{2MN-M-N}$$

$$S = \frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}(i+j)\sqrt{Re^2(i,j)+Im^2(i,j)}$$

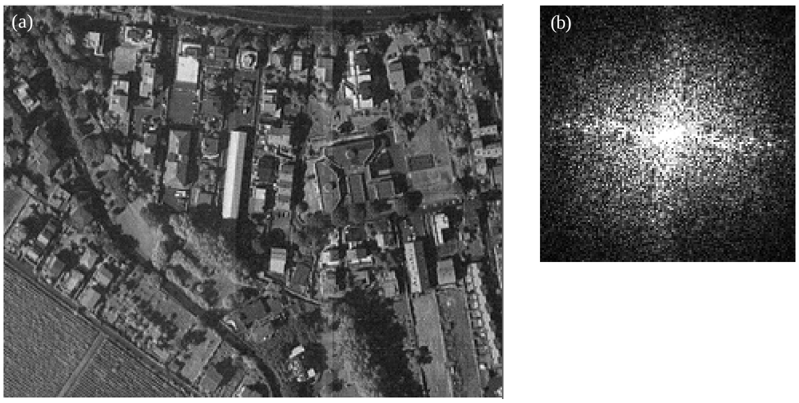

Fig. 3: Recovery results using the relations (17)

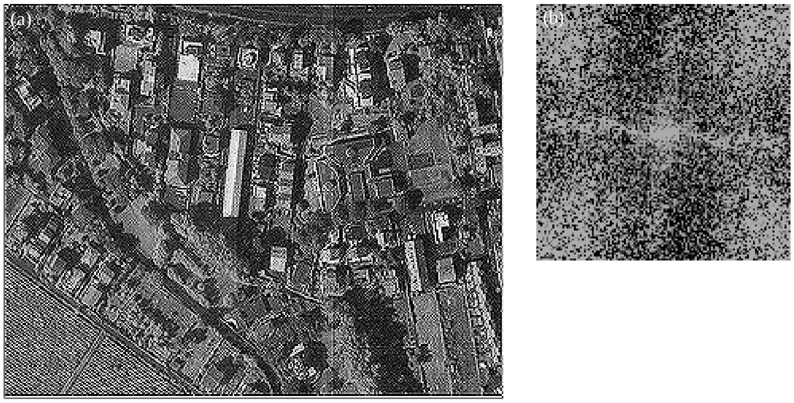

Fig. 4: The result of recovery without the use of relations (17)

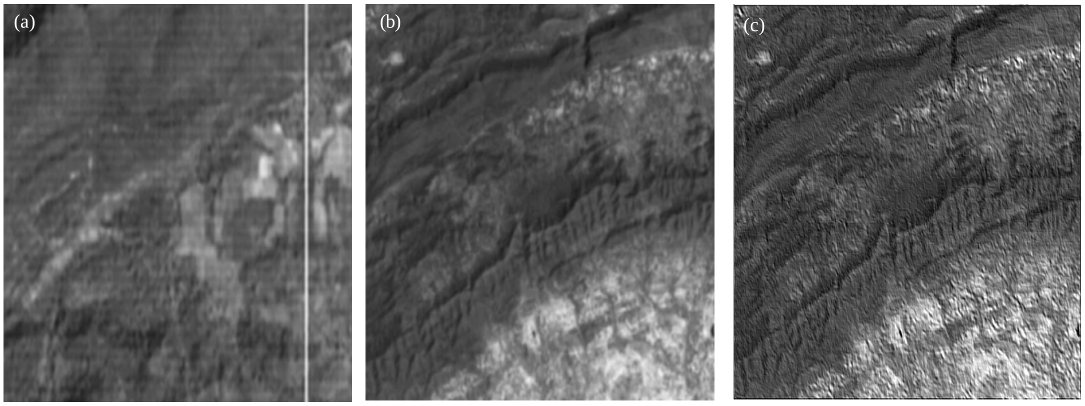

Fig. 5: The result of applying the method of image restoration in the presence of spurious bands: a) Portion of the image formed on the satellite "Monitor-E"; b) Fragment of the processed image iterative antimodulation technology; c) The reconstructed image with high sharpness (lambda = 0.9)

where, Re(i, j) and Im(i, j) the valid and imaginary parts of an element of a range of Fourier with coordinates (I, j). Table 1 shows comparision of image restoration methods. Sample processing test image 5 is shown in Fig. 6.

Analysis of the results leads to the conclusion that the developed image recovery method, based on the modification of Tikhonov operator, provides increase of recovery level up to 62% relative to existing methods.

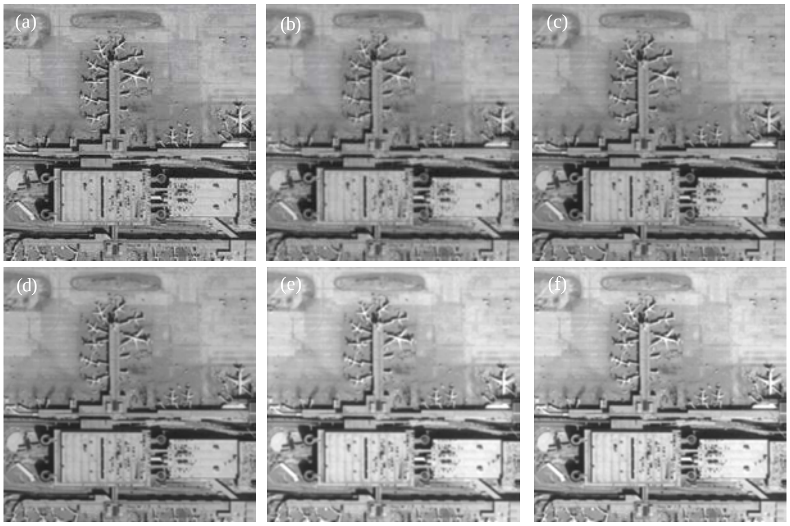

Fig. 6: Processing the test image 5. a) The original image; b) Defocused image; c) Van cittert method; d) Gold method; e) After selecting the parameters; f) The developed method

Table 1: Comparision of image restoration methods (TI test image)

Image	R, S	TI1	TI2	TI3	TI4	TI5	TI6	TI7
Image	R	60.54	100.76	128.03	75.37	337.63	118.01	2220.08
	S	6133.47	9664.14	10377.78	8489.09	16078.55	9679.53	29402.94
Defocusedimage	R	14.51	24.79	25.45	17.38	39.07	52.71	132.83
	S	3627.92	4720.80	4732.44	4322.72	5992.56	6890.23	10288.34
Van cittert method	R	35.41	40.00	44.18	29.35	54.23	77.27	341.24
	S	4850.99	6228.96	6351.31	5648.25	7241.38	8418.09	13795.63
Gold method	R	40.80	41.98	46.40	30.95	55.91	79.66	407.88
	S	5013.95	6405.82	6534.48	5807.17	7388.42	8574.08	14288.78
After selecting the parameters	R	21.90	43.54	38.96	27.90	59.87	80.27	175.37
	S	4442.84	6012.65	5835.95	5419.87	7389.00	8470.71	12387.24
The developed method	R	56.79	83.00	77.07	55.88	94.14	116.90	578.82
	S	6086.34	9030.62	8429.13	7702.23	9594.15	9438.56	18327.08

CONCLUSION

The method of recovery of satellite images of the Earth's surface, the distinguishing feature of which is a modification of the Tikhonov operator due to the additive that enhances the contribution of the high-frequency component with the parameter estimation compensation action point spread function directly from measurements while suppressing overopacification effect.

The process of determining the specific parameters, implemented in the developed method, allows to restore the quality of the image to make a full passport for metric certification of measuring properties of Earth surface images.

Prototype of the software implementation of image reconstruction algorithm that enables the practical implementation of the developed method for solving environmental monitoring, forecasting and management in technosphere safety areas for different purposes.

The results of computational experiments have shown that the application of this method allows to increase, the sharpness of the image on satellite images by 60% compared with existing methods.

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