APPLICATION OF WAVELET TRANSFORM FOR INTERNAL WAVE DETECTION IN SAR IMAGE

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Abstract

In this paper, wavelet transform based on dyadic scales and spatial location have been used for internal wave detection in SAR image. It performed by using multi resolution analysis of image for feature detection and image enhancement. Wavelet transform uses local analysis to analyze a shorter region in image in time and scale data allows precise information than time and frequency region analysis such as Fourier analysis. Internal wave is observed in SAR image by effect of Bragg scattering process in sea surface that represents the meso-scale feature of sea processes. SAR image data is used considering to the effectiveness of large scales area monitoring on near real time data. Internal waves were observed in ERS-1/2 SAR images data over Lombok Strait during 1996-2001 period using 2D Symlet analysis for the symmetric extension of data at the image boundaries, to prevent discontinuities by a periodic wrapping of data in fast algorithm and space-saving code. Lombok Strait is chosen as study area because this strait is a major passage of the flow from Pacific Ocean to Indonesian seas (ARLINDO) and passage of Indian Ocean Kelvin wave to Makassar Strait.

Keyword: SAR image, internal wave, wavelet analysis.

I. Introduction

Internal wave is a soliton-like wave with large amplitudes within several kilometers, which generally produced in upper layer of sea surface by tidal and atmospheric condition. Internal waves perturb current and density field, initiate bottom sediment re-suspension and mix nutrients to photic zone. **The** detection of internal wave would be necessary for the design of deepwater offshore production facilities (Colossi et.al. (2001)). Recently, SAR image data is frequently used to monitor various sea processes at and near sea surface such as internal wave because of the capability in large scales area of sea monitoring by using near real time data. In shallow waters, internal wave is visible by SAR image because its circulation modulate sea surface, cause a low linear bulge at surface, which is accompanied with distinctive pattern of small-scale surface waves. The circulation cell rises toward the sea surface at the trailing edge of an internal wave, which decreases the roughness of the small-scale surface wave and result in linear band of smooth water, called slick, parallel with the crest of internal wave then descends at the leading edge, causing **a** band of rougher water, called a rip band (Sabin et.al (1996)). This process affects to radar backscatter through Bragg scattering process, In the valleys of modulation wave, diffuse scattering occurs more than on crest lowering backscattering coefficient. Then, in SAR image the valley of wave appears darker than crest. In a wave packet, internal waves appear as dark and white strips in image correspond to slicks and rips band respectively (Jones et. al. (1993)). The length between crests in wave

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packet can be used to calculate the speed of internal wave. Then combined with seawater density, the oceanic mixed layer and the period of wave can be observed (Beer et. al. (1997)).

SAR image data is affected with speckle noise, a noise-like with random bright and dark pixels produced by radar waves due to the different distance of travel from targets, multiple bounce scattering or coherent processing of backscattered signal. Speckle noise reduction can be performed with standard speckle filter, such as Lee, Kuan, Frost or wavelet speckle filter. In previous research, wavelet speckle filter based on thresholding procedure performed equally as standard speckle filter for low-level noise (Gagnon et.al. (1997)), preserved edges and thin structure better (Liu et.al. (1997)). Meanwhile Gaussian wavelet transform is applied to track the evolution of meso-scale features such as oil spill, fronts, eddie, data reduction and image enhancement (Hervet et.al. (1998)). In image segmentation, wavelet domain classification is used with inherent tree structure of wavelet-domain hidden Markov tree models, its fast training, likelihood computation algorithm and a Bayesian probabilistic graph to perform multiscale texture classification at various scale and segment wavelet-compressed images without the need for decompression (Choi et.al. (1999)).

This paper analyzes the detection of internal wave and noise reduction in SAR image by using wavelet analysis. We studied the capability of wavelet transform with multi resolution analysis to analyze internal wave feature in image based on dyadic scales and spatial location. Wavelet coefficients of details and approximations of image and feature characteristic are recognized to delineate internal wave in image. Two-dimensional Symlet wavelet analysis is chosen to allow the symmetric extension of data at the image boundaries and prevents discontinuities by a periodic wrapping of data in fast algorithm and space-saving code.

II. Methodology

Quick look ERS-2 SAR image data over Lombok Strait on 1996 - 2001 period are used in detection of internal wave in SAR image. Lombok Strait is chosen as study area, because this strait is a major passage of the flow from Pacific Ocean to Indonesian seas (ARLINDO) and passage of Indian Ocean Kelvin wave to Makassar Strait. The simulation result confirmed that Kelvin wave from Indian Ocean propagated through Lombok Strait (Syamsudin (2002)). So far, the internal waves around Lombok Strait have been studied by using ERS SAR data. Internal wave affected radar contrast against the background and defined within relatively narrow darker band in image (Mitnik et.al. (2000)).

2.1. Wavelet Analysis

Wavelet analysis performs local analysis to analyze a shorter region in image in time and scale data. Thus it allows more precise information than time and frequency region analysis such as Fourier analysis. The two-dimensional wavelet is defined as tensor products of one scaling function and three wavelets. Wavelet transform is applied with: (1) the scaling equation to define the multi resolution approximation of image by taking account the low intensities of image, and (2) wavelet function to define the details of image corresponds to the high intensities of image. The discrete analysis is done with a successive process due to the type of wavelet transform for space-saving coding with sufficient synthesis. The representation of discrete analysis uses scale on dyadic bases from 2', 2^2,.., 2" and each coefficient of j level is repeated 2^J times. At each level of processing, an approximationof image, and deviation on horizontal, diagonal and vertical of image, are computed. Then, the next scaling-level of processing is the sum of approximation and deviation of previous level. A small-scale value of processing is used to perform a local analysis and a large-scale value is applied for global analysis. The resolution of image is increased as the scale of processing decreases and the detail become smaller and finer, if the resolution is increased. The scaling function and wavelet function are described as follows,

$$\phi(x) = \sqrt{2}\sum_k h_k \phi(2x-k)$$

$$\psi(x) = \sqrt{2}\sum_k g_k \phi(2x-k)$$

where ϕ is the scaling function, ψ is wavelet function, h_k is scaling filter and $g_k = (-1)^k h_{1-k}$

In this experiment, both scaling and wavelet value are applied to recognize the characteristic of image. Wavelet transform is known as Daubechies, Symlet, Bior, and Discreet Meyer wavelet based on its scaling and wavelet function. In this work, two-dimensional Symlet wavelet is chosen to allow the symmetric extension of data at the image boundaries and prevents discontinuities by a periodic wrapping of data. This wavelet is a nearly symmetrical wavelet adopted from Daubechies wavelet with orthogonal analysis and existence of scaling function, leads to fast algorithm and space-saving code. Symlet wavelet is described as follows (Misiti et.al. (1996)):

$$W(z) = U(z)\overline{U\left(\frac{1}{z}\right)}$$

where U > 1, with consideration that function as a function W of $z = e^{iw}$, which is applied on following equation:

$$|m_0(\omega)|^2 = \left(\cos^2\frac{\omega}{2}\right)^N P\left(\sin^2\left(\frac{\omega}{2}\right)\right)$$

which is derived from,

$$P(y) = \sum_{k=0}^{N-1} C_k^{N-1+k} y^k$$

$$m_0(\omega) = \frac{1}{\sqrt{2}}\sum_{k=0}^{2N-1} h_k e^{-ik\omega}$$

where m_0 is scaling function, P(y) is transfer function, Cf ~$^{1+}$* denotes the binomial coefficient and N is number of vanishing moments. Vanishing moments is a characteristic of wavelet to suppress a polynomial function. Higher number of vanishing moments smoothen wavelet function. The characteristic of Symlet wavelets with its scaling function is shown in figure 2. In this study, Symlet wavelet with different types (N=2,..,8) and level (J=l,..,5) are applied in synthesize image on horizontal, diagonal, and vertical of detail, and approximation to study the internal wave characteristic in image. Since SAR image consists speckle noise, which can reduce information in image, threshold is applied for noise reduction and image enhancement. Mean to standard deviation ratio is defined to compare the result of noise reduction.

III. Result and Discussion

Strong internal waves in the form of soliton group in ERS-2 SAR image were observed in Lombok Strait during 1996-2001 period by using 2D Symlet analysis. The occurrences of internal waves are described in table 1. The detection results show that strong internal wave in these images have higher wavelet coefficient than sea surface at detail and approximation of image from level 3 to 5 and created elongated pattern in image. Further detail is described below.

Symlet wavelet is applied with different coefficients and levels. Higher level of computation retain smoother version of image.

Table 1. The incidence of internal wave in ERS-2 SAR image

No.	Location and Date of Internal Wave Incidence	
	Lombok Strait	Near Kanggean Isl.
1	1996/4/23	1996/4/23
2	1996/4/24	-
3	-	1996/12/25
4	1997/7/7	-
5	1997/9/30	-
6	1997/10/1	-
7	1997/11/5	1997/11/5
8	1998/11/4	1998/11/4
9	1999/12/15	1999/12/15
10	1999/12/31	-
11	2000/1/19	-
12	2001/8/20	-
13	2001/9/5	-

Meanwhile higher coefficient compressed the wavelet. Higher coefficient (a = 5) attained the lowest standard deviation of image, reducing noise better than other level but loosing the feature size (table 2). Lower threshold between 4-6.5 is applied to maximize noise reduction in image. The profile of image's intensity before and after de-noise process is shown in figure 2. Image is viewed from the azimuth and elevation information.

Image intensity is proportional to backscattering of coefficient. The diffuse scattering of radar backscatter in valley of wave occurs more than on crest, lowering backscattering coefficient. Thus in profile of image intensity, the crest of internal wave appears higher than crest in profile (figure 2c, d). Considering to the other process over the sea, the condition over entire image is different, shown with the dark areas on left and right side of image, which is imaged with lower intensity in figure 2c, 2d. Figure 3 and 4 show the detection results of internal waves on November 5, 1997 and September 5, 1999. In figure 3, strong internal wave appears on top and bottom of images. Meanwhile in figure 4 shows weak internal wave at the same place shown with figure 3. In both figures, it is found that the crests of internal waves are detected on horizontal and vertical detail coefficient at level 3 to 5 with higher detail coefficient than sea surface correspond to the location of internal waves in right image. These features are detected at the top, middle and bottom of image, which creates elongated pattern in image. Strong internal wave is pointed by arrow. Figure 5 shows that the coastline and dark area near coastline also contribute strong variation of image values, which can be detected at the middle of image. On the top and bottom of image, the internal wave creates elongated pattern. The speed of internal wave can be measured from the distance between crests (figure 3). The wavelength of internal wave is about 5 km. The profiles of internal wave from detection result on horizontal level 3 of image with Symlet 3 and Symlet 8 are shown in figure 6. The crest of internal wave is pointed by arrow. The figures show the differences of crests height. The first wave height is reduced more with Symlet 8 and the height of small internal

Table 2. Mean and Standard Deviation of Each Level

Level (J)	Symlet 2		Symlet 3		Symlet 4		Symlet 5		Symlet 6		Symlet 7 •		Symlet 8	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
5	128.3	59.29	128.6	59.62	128.6	59.4	128.5	59.35	128.8	59.33	128.8	58.96	128.9	59.16
4	128.5	59.85	128.6	59.96	128.6	59.93	128.5	59.9	128.7	59.88	128.6	59.91	128.7	59.85
3	128.6	60.87	128.6	60.74	128.6	60.75	128.6	60.87	128.6	60.83	128.6	60.89	128.7	60.97
2	128.6	61.58	128.6	61.6	128.6	61.61	128.6	61.63	128.6	61.66	128.6	61.66	128.6	61.64
1	128.6	62.27	128.6	62.3	128.6	62.31	128.6	62.32	128.6	62.32	128.6	62.33	128.6	62.33
Input	128.6	63.06												

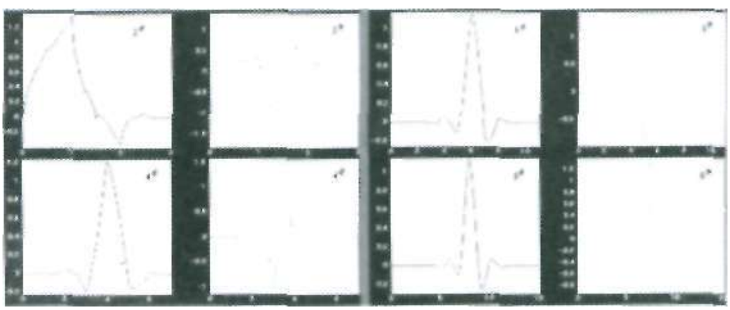

Figure 1. Plots of scaling function N[r] and wavelets N* for Symlet wavelet with maximum number of vanishing moments, for N = 2,4,6, and 8.

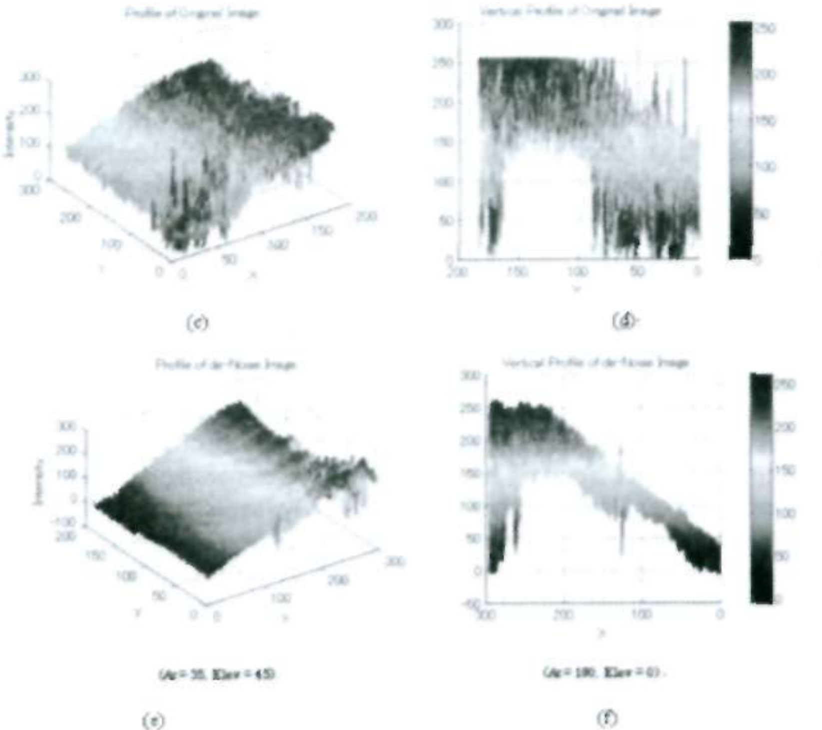

Figure 2. Reconstructed image of quick look of ERS SAR image (upper). Profil of image's intensity before and after de-noise process (middle-lower). Image is viewed from the azimuth and elevation information. The crests of internal wave have higher backscattering coefficient than its valley.

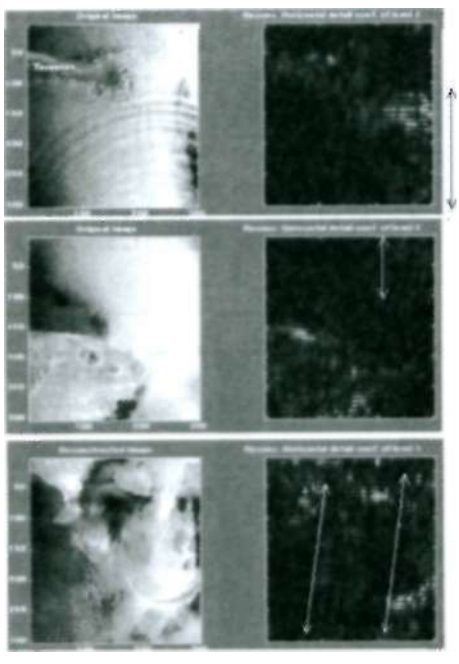

Figure 3. Quick look images of ERS SAR data and Symlet analysis result on horizontal detail coefficient of level 3 (1997/11/5). Crests of internal waves arc pointed by arrow on right in image.

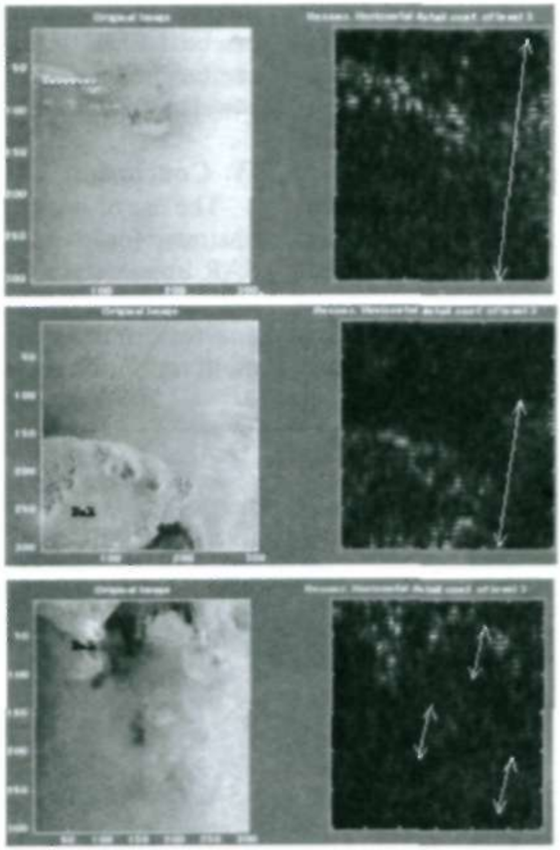

Figure 4. Quick look images of ERS SAR data and Symlet analysis result on horizontal detail coefficient of level 3 (1999/12/15). Crests of internal wave are pointed by arrow.

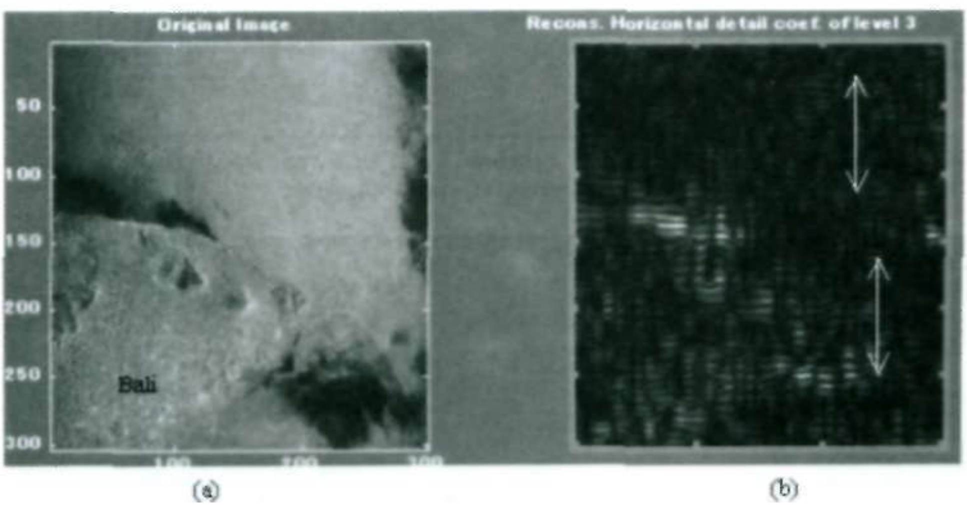

Figure 5. Quick look images of ERS SAR data and Symlet analysis result on horizontal detail coefficient of level 3 (1999/9/5). Crests of internal wave (upper) and sea process are pointed by arrows. At the middle of image, the coastline and dark area near coastline contribute sharp variation of image values which can be detected on image. On the top and bottom of image, the internal wave create elongated pattern in image.

waves can be seen clearly with Symlet 3. The vanishing moments and scaling filter for Symlet 3 and Symlet 8 are 3, 6, 8 and 16 respectively. It shows that higher number of vanishing moments smoothen wavelet function, and decreasing wave height.

Internal wave detection can be detected clearly compare to figure 2 on which high backscattering coefficient dominates on left side of image make difficulty in crest measurement. The detection result on level 5 is shown in figure 7. The elongated pattern is imaged clearly and the distance between crests can be defined through the sharp different of coefficient detail in image. In other hand, the wavelength cannot be measured precisely.

IV. Conclusion

The use of wavelet analysis has been demonstrated for internal wave analysis in ERS-2 SAR images data. The wavelet transform of images can be used for image enhancement and feature detection and has advantage in multi resolution and spatial analysis to detect

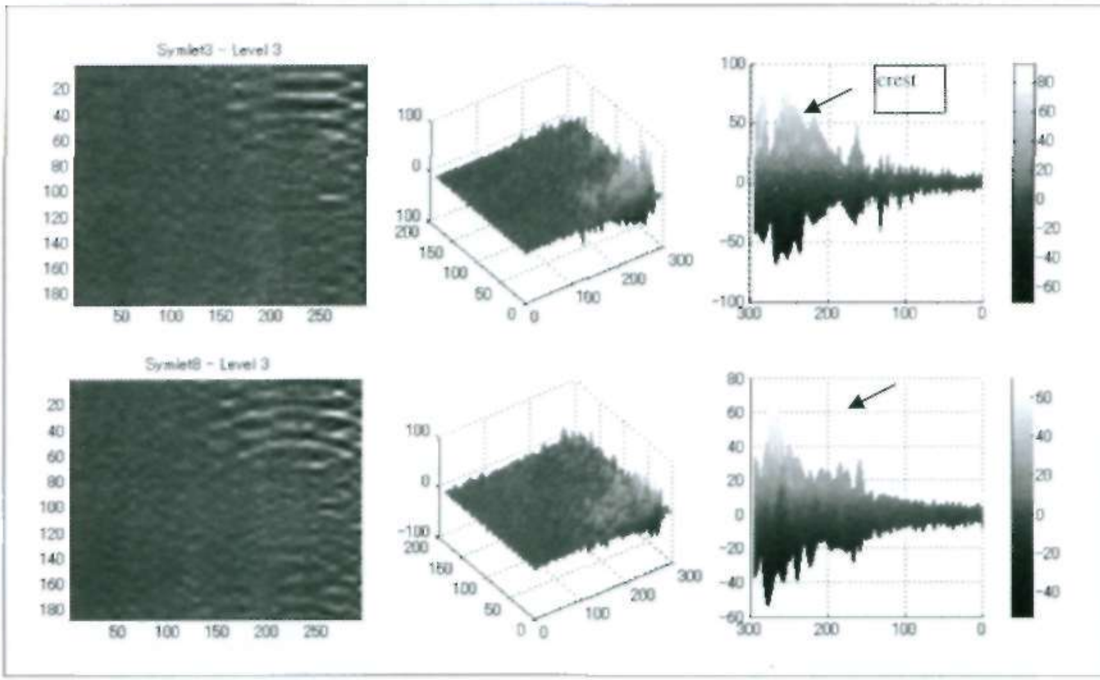

Figure 6. Detection result on horizontal coefficient level 3 of Symlet 3 and Symlet 8 with its profiles. Crest of internal waves is shown with arrow.

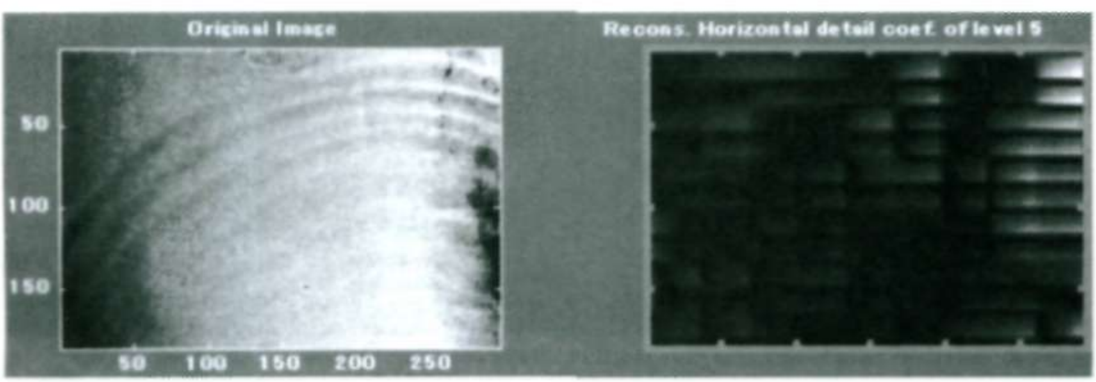

Figure 7. Detection result on horizontal detail level 5 of image

internal wave in SAR image.

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