The Progressive Transmission Method Based on the 2–D Wavelet Transform for a Digital Video Signal[1]

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Abstract. This paper presents a method of progressive digital transmission of a video stream, based on picture frame multi-resolution analysis.

1. Introduction

In today's computer systems (Figure 1) the low capacity of connectors is a major obstruction in the case of smooth digital transmission of video pictures. Regular and supervising video transmission systems belong to the "real time class systems."

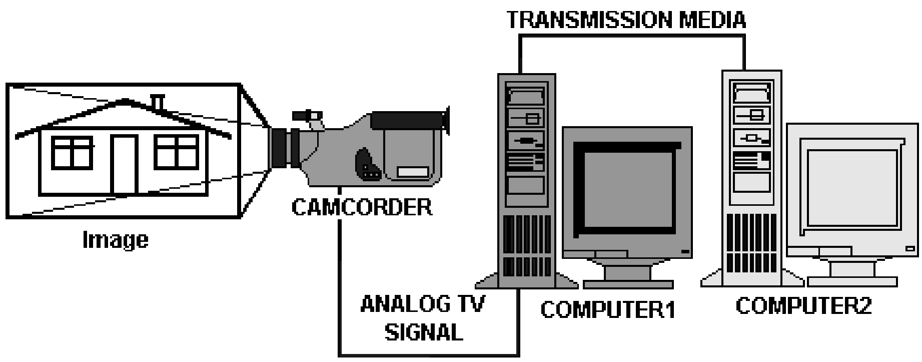

Figure 1. Picture transmission in a network computer system

The most decisive factor of applicability is the maximum reaction time of the system to a start up event. The acceptable time depends on how fast the changed video picture can be reloaded and observed in real-time. Slow reaction time can make a system not applicable. In this paper a progressive method for transmission video image is presented. The adaptability of transmitted image resolution to the dynamics of picture motion changes is proposed.

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2. Problem definition

In this paper a video digital transmission is understood as a transfer of frame sequences, where each frame is defined as a raster picture. The raster picture of a given resolution is represented as the following function:

$$O : P \rightarrow Z\,, \tag{1}$$

where:

$P = [1,\ldots,\overline{L}_R] \times [1,\ldots,\overline{L}_C] \subset N^2$

$\overline{L}_R$ – number of frame rows

$\overline{L}_C$ – number of frame columns

Z – colour representation.

The frame transmission time can be calculated by the formula:

$$T = \frac{\overline{L}_B \times \overline{L}_P}{\overline{P}_T}\,, \tag{2}$$

where:

$\overline{L}_P = \overline{L}_R \times \overline{L}_C$

$\overline{L}_B$ – number of bits per pixel of an image [bit/pixel]

$\overline{P}_T$ – transmission speed [bps].

If an image transmission time T is greater than required time T_R of system reaction, the following solution is proposed: to change a frame resolution in order to reach the following inequality:

$$4^{-n} \cdot T \leq T_R\,. \tag{3}$$

Parameter n describes the resolution of the transmitted image L_P:

$$L_P = L_R \times L_C\,, \qquad \text{where:} \quad L_R = 2^{-n} \cdot \overline{L}_R\,, \quad LC = 2^{-n} \cdot \overline{L}_C\,. \tag{4}$$

The standard of the measurement of the picture transmission is defined as a unit-image of a given resolution. Therefore transmission time depends more on picture size and its resolution than on the transfer of the real information. The presented method of progressive transmission of a video picture is a compromise between real-time transmission and picture quality. It is proposed to manipulate picture resolution as a function of its dynamic changes. In the case of high dynamic changes, the frames should have smaller resolution, otherwise progressive detailing of a transmitted picture frame should be applied. The progressive transmission means that the image resolution can be enlarged. The pyramid coding method makes it possible. The pyramid coding method can be used if the picture is represented by the wavelet transform. The transmission process depends on whether a next frame differs from a previous one. If it does not, than the old frame continues to be transmitted. If the next frame is different from the preceding one, the transmission of the old frame stops and the next frame starts to be transmitted.

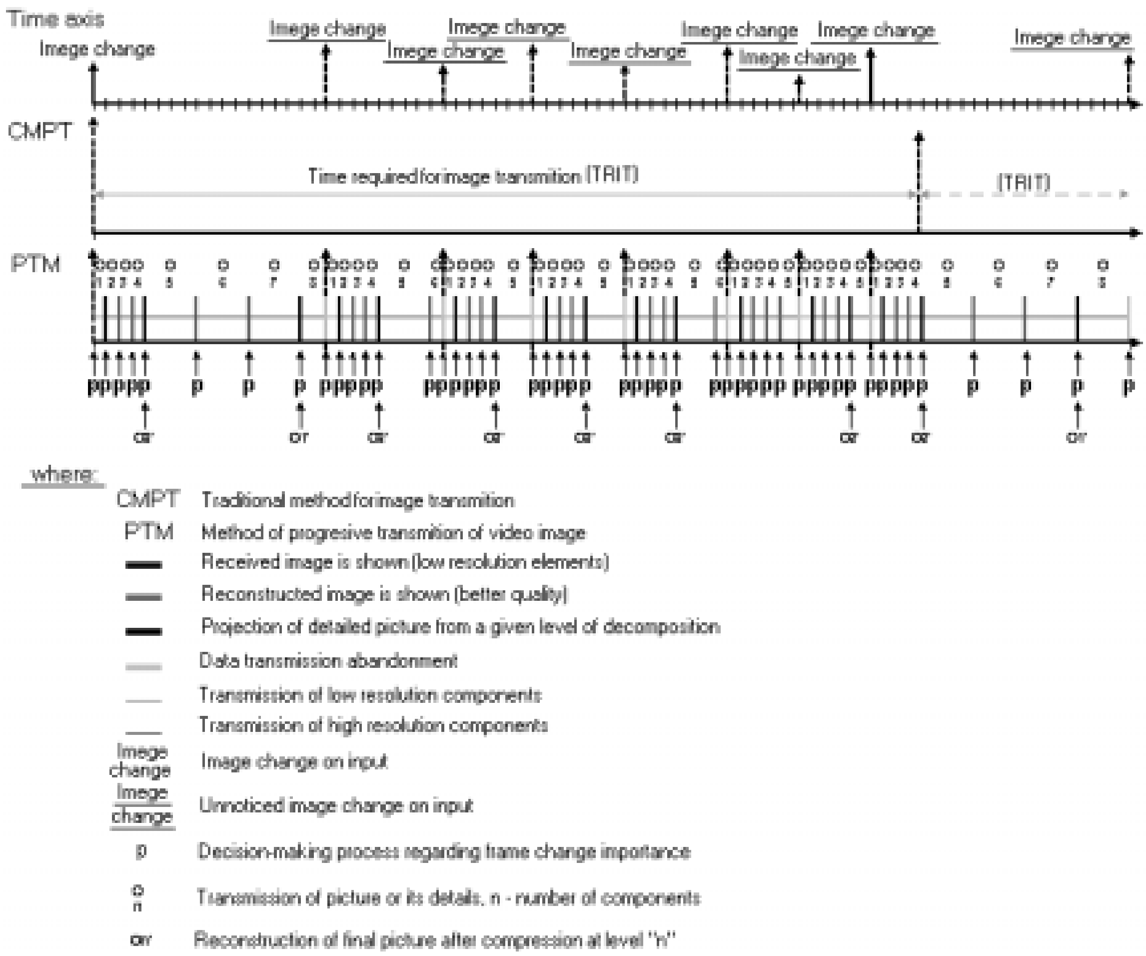

Figure 2. Picture transmission in a network computer system

The decision whether a difference exists between the frames is based on analysis of a picture histogram. Although this procedure of finding the threshold of experimentally determined median of a frame histogram is a quite complicated, but it is efficient. The progressive transmission of a picture provides a compromise between required reaction time of a computer system and the requirement for transmitting a picture in original resolution. The initial transfer of a transmission quant guarantees a picture reproduction in minimal resolution. The absence of changes in a frame causes the additional transmission quantum to be delivered; this results in improving picture quality.

The explanation of the progressive transmission is presented in Figure 2. At the initial time $T = 0$, the histogram median value reaches a maximum which causes the delivery of one transmission quant to the receiver. This quant represents the picture at the smallest resolution (O1 – block No.1 in Figure 5c). If the analysed frame does not change, the receiver obtains details from a given level of decomposition; blocks No. 2, 3, 4 (Figure 5c). After the transmission of all the details from a given level of the picture decomposition, the analyser shifts the decomposition level from higher level to the lower level. Transmission of additional details of the analysed picture (blocks 5, 6, 7 in Figure 5c) improves the final frame quality. After definite time, if no changes in the input picture are observed, the original quality of the picture is obtained.

3. Wavelet transformed picture representation

3.1. Image decomposition

The rows of picture are passed through low-pass (block L) and high-pass (block H) filters. Pictures obtain from filtration are sampled again with regard to columns, where every even element of sequence (block 2↓1 in Figure 3) is omitted. The repetition of low-pass and high-pass samples the rows of the obtained picture in the previous step. In this process every even element in sequence (block 1↓2 in Figure 3) is omitted. It gives the first level of decomposition of a picture in the wavelet transform. The elements of this representation are described below:

$Image(LL)_{j+1}$ – low resolution elements with respect to rows and columns of the picture

$Image(LH)_{j+1}$ – low resolution elements with respect to rows, high resolution elements with respect to columns of the picture

$Image(HL)_{j+1}$ – high resolution elements with respect to rows, low resolution with respect to columns of the picture

$Image(HH)_{j+1}$ – high resolution elements with respect to rows and columns of the picture.

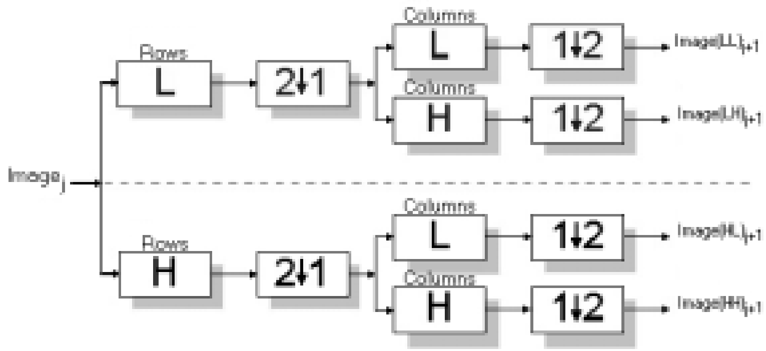

Figure 3. First level decomposition of the picture (DWT2)

The picture decomposition for $n = 3$ means triple recalculation of the 2-D wavelet transform. The diagram of three-level decomposition of a raster picture is represented in Figure 4.

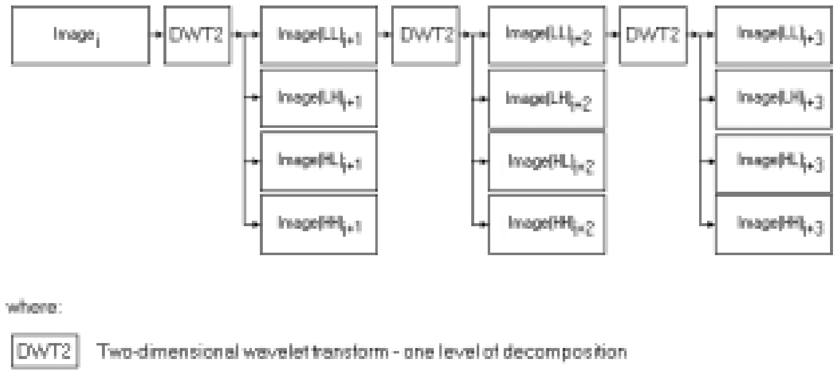

Figure 4. Three-level picture decomposition

The symbols used in Figure 4 denotes as follow:

- $Image_j$ – Image assigned for decomposition
- $Image(LL)_{j+1}$ – Low resolution elements with respect to rows and columns of the picture
- $Image(LH)_{j+1}$ – Low resolution elements with respect to rows, high resolution with respect to columns of the picture
- $Image(HL)_{j+1}$ – High resolution elements with respect to rows, low resolution with respect to columns of the picture
- $Image(HH)_{j+1}$ – High resolution elements with respect to rows and columns of the picture
- $Image(LL)_{j+2}$ – Low resolution elements with respect to rows and columns of the picture
- $Image(LH)_{j+2}$ – Low resolution elements with respect to rows, high resolution with respect to columns of the picture
- $Image(HL)_{j+2}$ – High resolution elements with respect to rows, low resolution with respect to columns of the picture
- $Image(HH)_{j+2}$ – High resolution elements with respect to rows and columns of the picture
- $Image(LL)_{j+3}$ – Low resolution elements with respect to rows and columns of the picture
- $Image(LH)_{j+3}$ – Low resolution elements with respect to rows, high resolution with respect to columns of the picture

- $Image(HL)_{j+3}$ – High resolution elements with respect to rows, low resolution with respect to columns of the picture
- $Image(HH)_{j+3}$ – High resolution elements with respect to rows and columns of the picture.

The decomposed image (for $n = 1$) is understood as a picture received from a camera. In order to continue calculations of the wavelet transform (for $n = 2$, $n = 3$) the obtained picture (the result of a low-capacity filtration with respect to rows and columns, received in a prior transform calculation, $n = 1$) must be treated as the input one. An example in Figure 5 shows a picture decomposition for $n = 3$. The images from left to right show: the picture obtained from a camera, the wavelet transfer representation of the picture, numbered blocks which represent wavelet format of the picture respectively.

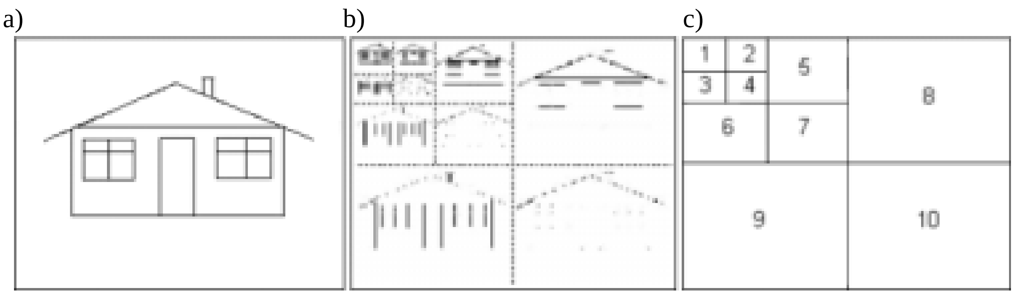

Figure 5. Example of raster picture decomposition for n=3

3.2. Image reconstruction (Figure 6)

The image reconstruction is understood here as a regeneration of frame $Obraz_j$ from its components, received during the decomposition process:

$$Image(LL)_{j+1},\ Image(LH)_{j+1},\ Image(HL)_{j+1},\ Image(HH)_{j+1}.$$

Image reconstruction starts with the sampling of pictures column (block 2↑1): $Image(LL)_{j+1}$, $Image(LH)_{j+1}$, $Image(HL)_{j+1}$, $Image(HH)_{j+1}$, simultaneously after each element of the sequence element “zero” is being added. Rows of received pictures pass by a low-pass filter (block L) and high-pass filter (block H). The results of filtration are added and sampled again by rows (block 1↑2), similarly to sampling columns in a previous step. At this point result of the filtration have been obtained. The sampling of these results by columns (low-pass filtration (block L) and high-pass filtration (block H)) gives two medial pictures. Summation (block F) of all these pictures results in obtaining the image $Image_j$ which is equal to the input image in the decomposition process.

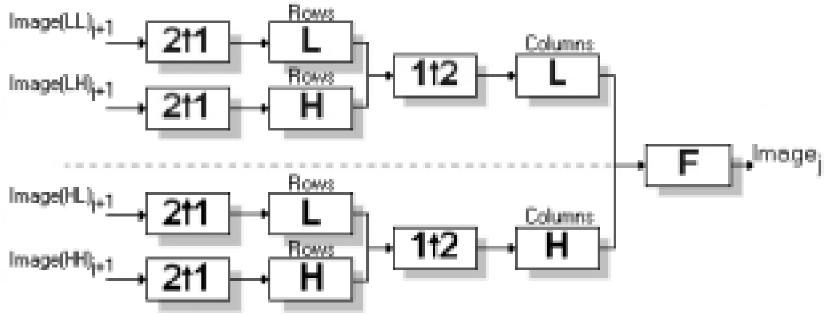

Figure 6. One – level reconstruction of a picture

The diagram of the three-level ($n = 3$) reconstruction of a raster picture is presented in Figure 7, all terms have been explained in section 3 (entitled "Picture decomposition").

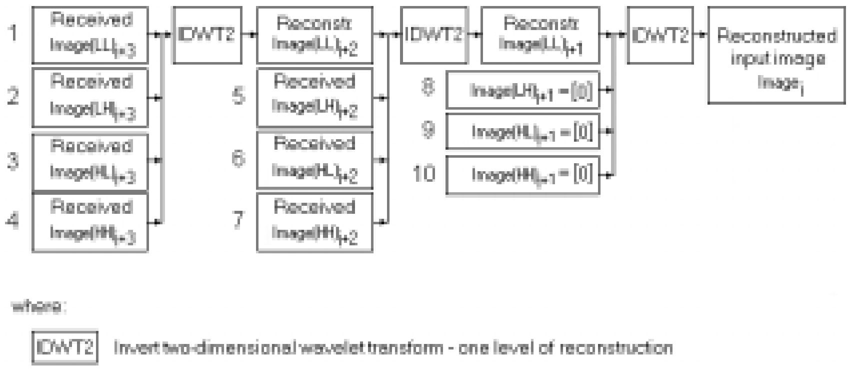

Figure 7. Reconstruction process in the case of the wavelet transform

The reconstruction of a picture (for $n = 3$) requires triple calculations of the 2-D inverse wavelet transform. The reconstructed image (for $n = 3$) can be identified with a picture represented by elements received during the first quant transmission $Image(LL)_{j+3}$. For the lower reconstruction level ($n = 2$, $n = 1$) the picture is reconstructed from the one received in the previous step. An example of reconstructed picture (for $n = 1$) is presented in Figure 8b.

a) b)

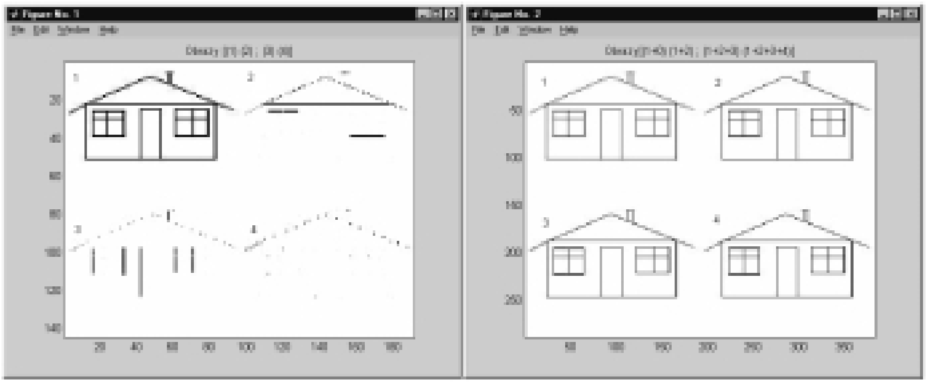

Figure 8. Exemplary results of the decomposition and reconstruction of a frame

Figure 8a shows results received during the frame decomposition for $n = 1$

- $Image(LL)_{j+1}$ – image 1
- $Image(LH)_{j+1}$ – image 2
- $Image(HL)_{j+1}$ – image 3
- $Image(HH)_{j+1}$ – image 4.

Figure 8b represents results received during the reconstruction:

- $Image(LL)_{j+1}$ together with zero matrix – image 1
- $Image(LL)_{j+1}$ and $Image(LH)_{j+1}$ – image 2
- $Image(LL)_{j+1}$, $Image(LH)_{j+1}$ and $Image(HL)_{j+1}$ – image 3
- $Image(LL)_{j+1}$, $Image(LH)_{j+1}$, $Image(HL)_{j+1}$ and $Image(HH)_{j+1}$ – image 4.

The algorithm of decomposition and reconstruction of an image (for $n = 1$) can be presented with the following procedure in Matlab environment:

<u>Picture decomposition:</u>

image1 = dyaddown(conv2 (image, L_D),'c'); //

image_LL = dyaddown(conv2 (image1, L_D'),'r'); // Image $(LL)_{i+1}$

image_LH = dyaddown(conv2 (image1, H_D'),'r'); // Image $(LH)_{i+1}$

image1 = dyaddown(conv2 (image, H_D),'c');

image_HL = dyaddown(conv2 (image1, L_D'),'r'); // Image $(HL)_{i+1}$

image_HH = dyaddown(conv2 (image1, H_D'),'r'); // Image $(HH)_{i+1}$

<u>Picture reconstruction:</u>

```
image_LL_1 = dyadup (image_LL, 'r');
image_LH_1 = dyadup (image_LH, 'r');
t1         = conv2 (image_LL_1,L_R');
t2         = conv2 (image_LH_1,H_R');
t0         = t1+t2;
image_HL_1 = dyadup (image_HL, 'r');
image_HH_1 = dyadup (image_HH,'r');
d1         = conv2 (image_HL_1,L_R');
d2         = conv2 (image_HH_1,H_R');
d0         = d1+d2;
image1     = conv2 (dyadup(t0,'c'),L_R);
```

```
image2      = conv2 (dyadup(d0,'c'),H_R);
image       = image1+ image2;
rozmiar     = 2*size (image_LL) - length(L_R)+2;
imagew      = wkeep (image,rozmiar);
```

where:

L_D – vector of low-pass filter coefficients, used during decomposition
L_R – vector of low-pass filter coefficients, used during reconstruction
H_D – vector of high-pass filter coefficients, used during decomposition
H_R – vector of high-pass filter coefficients, used during reconstruction.

In the case, when wavelet proposed by Haar is used, the following vectors describe filters:

L_D = [0.70710678118655 0.70710678118655]
L_R = [0.70710678118655 0.70710678118655]
H_D = [– 0.70710678118655 0.70710678118655]
H_R = [0.70710678118655 – 0.70710678118655].

4. Decision factors - whether the picture is changed or not

The decision about continuation or repetition of transmission can be based on the differential analysis of a picture for two different frames, the one being transmitted and the other one received from a camera. It is proposed to use a value of histogram median of differential picture as a major factor in the decision process.

The histogram of a differential picture is presented by the following formula:

$$H_R : C \to N \cup \{0\}, \tag{5}$$

where N is the natural number class. $H_R(c)$ is the number of repetitions for colour c in the differential picture R.

Decision – making is described by the following formula:

$$D(m(H_R)) = \begin{cases} d1, & \text{for } m(H_R) < \overline{w}_1 \\ d2, & \text{for } m(H_R) \le \overline{w}_1, \end{cases} \tag{6}$$

where:

$m(H_R)$ – histogram median of differential picture H_R
d_1 – acknowledgement about no changes in the picture
d_2 – acknowledgement about existence of changes in the picture

$\overline{w}_1$ – threshold value.

The threshold value $\overline{w}_1$ was determined experimentally. In the practical application (for the resolution $\overline{L}_R \times \overline{L}_C = 144 \times 192$ and number of bites per colour $\overline{L}_B = 24$) the threshold was equal to 4 ($\overline{w}_1 = 4$).

5. Determination of data transfer sequence

The test was conducted in order to determine whether the sequence of data transfer could influence the improvement of a frame quality. The result of the experiments did not show any correlation. It has been proved that the sequence of details being added from the same level of the picture decomposition do not influence the quality of a picture obtained during the reconstruction process. The Hilbert curve H_K algorithm was used (for $K = 3$) in order to obtain the sequence of the quants transmission (see Figure 9).

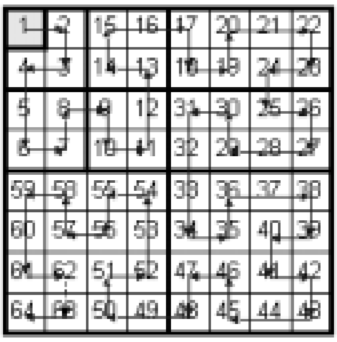

Figure 9. The sequence of data transmission

6. Final remarks

1. The process of image reconstruction can be synchronised with the stop event of the transmission. It results in decreasing of the reconstruction time.
2. It is easier to calculate the inverse wavelet transform for any stage of the transmission if all the received coefficients are being written down in zero matrix. However, it makes the time of calculations longer.
3. The wavelet transform is represented by real numbers. It may be unprofitable for the coefficients transfer (increases the number of bits per pixel)

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