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by

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ENCODING MOVING PICTURE BY USING ADAPTIVE STRAIGHT LINE APPROXIMATION

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Summary

There are several methods to deal with the problem of redundancy reduction in encoding a moving picture (e.g. conference television or picture-phone). In this paper another method is presented. For a moving picture the only information that has to be transmitted is the information of the moving parts. Because of the poor resolution of the human eye in the moving part of the picture, one can transmit an approximation of the signal.

A Kalman filter is used to obtain a straight line approximation to the signal on the moving part. Since the human eye is less sensitive to errors in the intensity at higher value of this intensity, the Kalman filter is designed so as to emphasize intensity errors at lower values of the intensity.

In order to encode the straight line approximation of the signal it is sufficient to encode their breakpoints. Consequently, the information one has to send are the positions and the amplitudes of the straight line approximation. By considering the dependence of the position and the amplitude of a breakpoint on a line with respect to those on the adjacent lines, more redundancies can be removed.

On the onther hand, viewers need much clearer details on the stationary part. In order to suit to this requirement, as soon as an uncovered background is recognized, the compensating signal is added to it.

I. Introduction

There are many redundancies among picture elements, lines and frames in television signals. For transmission or storage of television scenes people want to use the channel capacity efficiently or keep the storage medium size as small as possible. Since more than ten years, many efforts have been made in encoding television signals [1-9]. Owing to the reliability and flexibility of digital signal in transmission, storage and processing, and also due to the rapid development of LSI--scale increasing, speed increasing, reliability increasing and price decreasing--many people have been attracted to work in the field of digital television signal encoding, and many systems have achieved working in real time.

Yan and Sakrison proposed an image source model when they are encoding still pictures [11,12]. According to this model, an image source produces two components: a discontinuous component and a remainder. The discontinuous component is with respect to contours and shadows of objects. The remainder corresponds to details of objects. Before doing this work, the author used this model splitting these two components of difference of two images from the difference signal between two successive frames of television signals by means of an adaptive Kalman filter. Due to the poor resolution of human vision in the moving parts of a scene, the discontinuous component was encoded instead of the original difference signal. A good result was obtained [13].

Because of the different human visual characteristics in the moving part and stationary part of a scene, and because in many cases people would like to pay much attention to the stationary part, hence the stationary part should be kept much clearer than the moving part. Therefore the tolerable distortions of scene on the moving part and stationary part are different. In this paper a moving picture is considered as three parts. (1) Moving part, which is the part different from the previous frame. This part is created by moving objects, eg. a moving object is occupying a new position, or some new background is being uncovered. In this part only the discontinuous component is encoded. The discontinuous component signal consists of several successive straight line segments, which are split from the original signal by Kalman filtering along the scanning line. (2) New background, which belonged to a moving part in the previous frame but is a stationary part in the current frame. It is likely to be a part of background uncovered in the previous frame or a part of moving object which stopped its motion for example. In this part, we transmit a compensating signal adding to the straight line approximation of the previous frame. Hereafter this part is refered to as the compensating part. Taking this measure enables the background to be kept clearer and also makes it possible to use different visual distortion criteria on the moving part and stationary part of a scene. (3) Still part. No significant change is found in this part, so no information need to be sent.

Hence, in order to encode a successive television signals, at first, we compare the corresponding two lines of successive frames, to get the most significantly changed parts. We then let the signal in the moving part pass through a Kalman filter obtaining its straight line approximation segments. Obviously, to encode these straight line segments it is enough to encode their breakpoints. In the encoding procedure, taking advantage of dependencies of breakpoints among lines and frames makes coding scheme more efficient. To encode a compensating signal, only amplitude information is necessary. Additional address information is of no need. This will be discussed for the time being.

II. Moving part processing.

In a moving part of a picture, the signal is different from the previous frame. In general, a moving scene is not easily to track by a viewer. Investigation of human visual response to a moving picture is still in an early stage, but some results tell us that the resolution of the human eye in a rapidly changing picture is very poor: to recover normal resolution takes about 0.75 sec. [14]. In addition, in many cases people do not pay much attention to the details of the scene in a moving part. Based on this point, we encode the discontinuous component of the image in the moving parts instead of encoding the image itself.

The discontinuous components of an image can be considered as being some approximation of the image signal. Straight line approximation is one of the efficient methods [15,16]. We use a Kalman filter [16] to obtain the straight line approximation. Since using a Kalman filter means getting the minimum weighted mean square error, it enables encoding the compensating signal, which is the errors in the procedure of Kalman filterring, with higher efficiency.

As a straight line model of the discontinuous component of an image, the straight line can be expressed by its starting point (1,A) and slope S, shown in Fig. 1 .

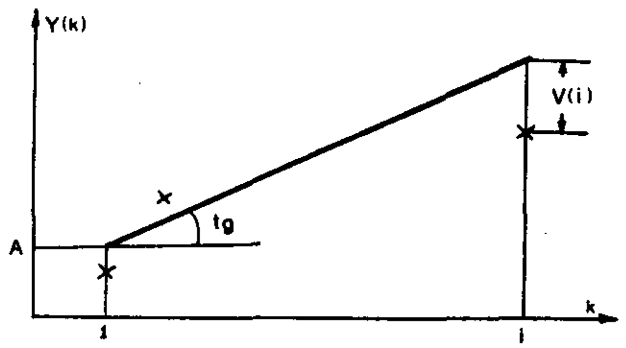

Fig. 1. Straight line model x--intensity sample.

Then the state transition equation can be written as

$$\begin{bmatrix} A(k) \\ s(k) \end{bmatrix} = \begin{bmatrix} A \\ S \end{bmatrix}$$

The observation equation is

$$Y(k) = \begin{bmatrix} 1 & (k-1) \end{bmatrix} \begin{bmatrix} A \\ S \end{bmatrix} + V(k)$$

where Y(k) is the intensity of the k-th sample of the image signal, and V(k) is error. In fact V(k) is the k-th sample of the remainder.

The variance of V(k) is

$$R(k) = E\left[v^2(k)\right] = q(k)e^2$$

where e^2 is constant, q(k) is a weighting factor, which is dependent on the intensity of the k-th sample of the image signal, is a time-variant function. Therefore, we can obtain the k-th estimation of the parameters

$$\begin{bmatrix} A(k) \\ S(k) \end{bmatrix} = \begin{bmatrix} A(k-1) \\ S(k-1) \end{bmatrix} + [K(k)] \left[Y(k) - [1 \ (k-1)] \begin{bmatrix} A(k-1 \\ S(k-1) \end{bmatrix} \right]$$

The gain matrix is

$$[K(k)] = [p(k-1)] \begin{bmatrix} 1 \\ k-1 \end{bmatrix} \left[[1 \ (k-1)] \ [p(k-1)] \begin{bmatrix} 1 \\ k-1 \end{bmatrix} + R(k) \right]^{-1}$$

While the error covariance matrix is

$$[p(k)] = [p(k-1)] - [K(k-1)] \ [1 \ (k-1)] \ [p(k-1)]$$

The calculation can be started from

$$\begin{bmatrix} A(1) \\ S(1) \end{bmatrix} = \begin{bmatrix} Y(1) \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} A(2) \\ S(2) \end{bmatrix} = \begin{bmatrix} Y(1) \\ Y(2) - Y(1) \end{bmatrix}$$

$$[p(2)] = \begin{bmatrix} q(1) & -q(1) \\ -q(1) & q(1)+q(2) \end{bmatrix} e^2$$

After determining the weighting factor q(k), the iterative solution of the estimation of the segment parameters will be available.

III. Segmentation of the straight line approximation and determination of the weighting factors.

We split the discontinuous component from the image along every scanning line. A discontinuous component consists of a series of straight line segments. In a procedure of Kalman filtering, when there are two consecutive errors greater than some threshold, a new straight line segment is chosen, and an end point and a new starting point are generated. This provides that breakpoints mostly occur at edges of objects, and it also smoothes out some isolated noise. It is obvious that the higher the threshold is, the less the number of segments will be.

The intensity error sensitivity of the human eye has very complicated properties [14,18]. It depends on the picture statistics very much. Fig. 2 shows the minimum distinguishable intensity error D of human vision as a function of the intensity I in a test region R for various background intensities IO.

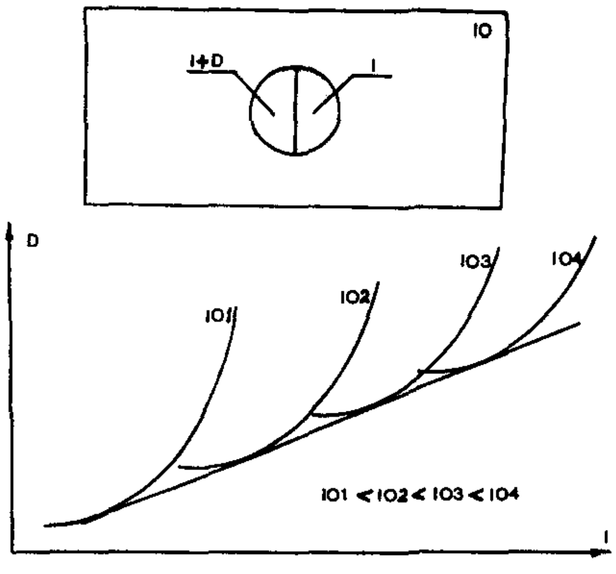

Fig. 2; The human eye's distinguishable errors of intensity.

In practice it is also dependent on, for example, the sharpness of the image boundary and so on. Therefore when the background is more complicated, as the real scene on the television, the human eye is not sensitive to the relative contrast (Weber's law). Statistically, without considering the r-effect of the picture tube, the higher the intensity is the less the sensitivity should be expected. It seems impossible to estimate the best rule for this phenomenon at this stage. Considering also the r-effect of the picture tube, our scheme is simply treating the tolerable intensity error of the human eye as two segments of straight line shown in Fig. 3 .

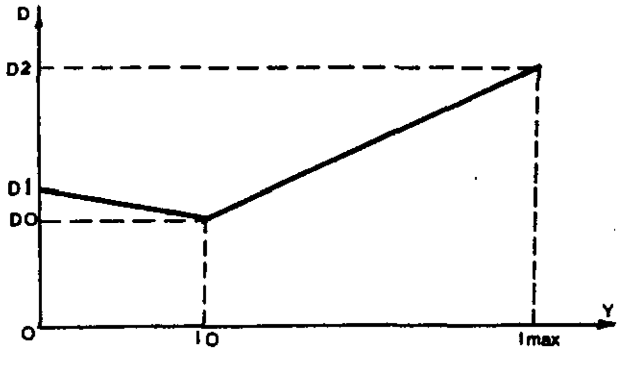

Fig. 3, Tolerable intensity error as two segments of straight line.

Therefore the error threshold can be expressed as a function of intensity

$$D(Y) = \begin{cases} \dfrac{D2-D0}{Imax-I0}\ (Y-I0) + D0 & \text{when } Y \geq I0 \\[2ex] \dfrac{D1-D0}{I0}\ (I0-Y) + D0 & \text{when } Y < I0 \end{cases}$$

where D1--the given error threshold at intensity 0, D0--the given error threshold at some given intensity I0, D2--the given error threshold at maximum intensity value Imax, and D--the error threshold estimated at intensity Y.

All the values of D1,D0,D2, and I0 should be chosen in accordance with the picture statistics.

Since a Kalman filter makes least mean square errors, the relation between the weighting factor and the intensity error threshold can be expressed as

$$q(Y).D^2(Y) = q(I0).D0^2$$

let q(I0) be 1, then

$$q(Y) = \begin{cases} \left\{ \dfrac{D0}{\dfrac{Y-10}{Imax-I0}\ (D2-D0)+D0} \right\}^2 & \text{when } Y \geq I0 \\[3ex] \left\{ \dfrac{D0}{\dfrac{Y}{I0}\ (D1-D0)-D1} \right\}^2 & \text{when } Y < I0 \end{cases}$$

Fig. 4 shows the threshold and weighting factor curves against intensity under some given parameters.

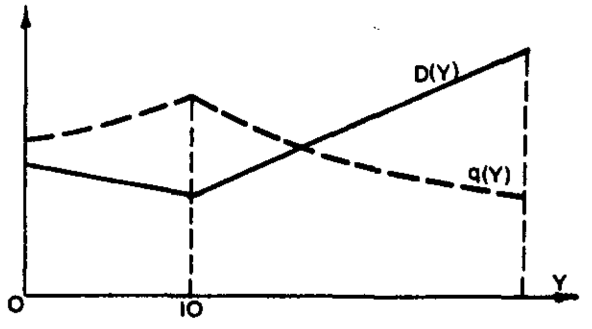

Fig. 4. Threshold D(Y) and weighting factor q(Y).

Fig. 5 shows a practical processing procedure along a television scanning line. Fig. 5b shows the line processed on the current frame. Fig. 5a shows the corresponding line on the previous frame. Fig. 5e shows the difference between the two lines and the corresponding thresholds. Fig. 5d shows the encoded signal--the straight line approximation in the moving part. Fig. 5c shows the reconstructed signal of the line. In the stationary parts, it is the signal of the previous frame while in the moving part it is the straight line approximation of the signal in the current frame.

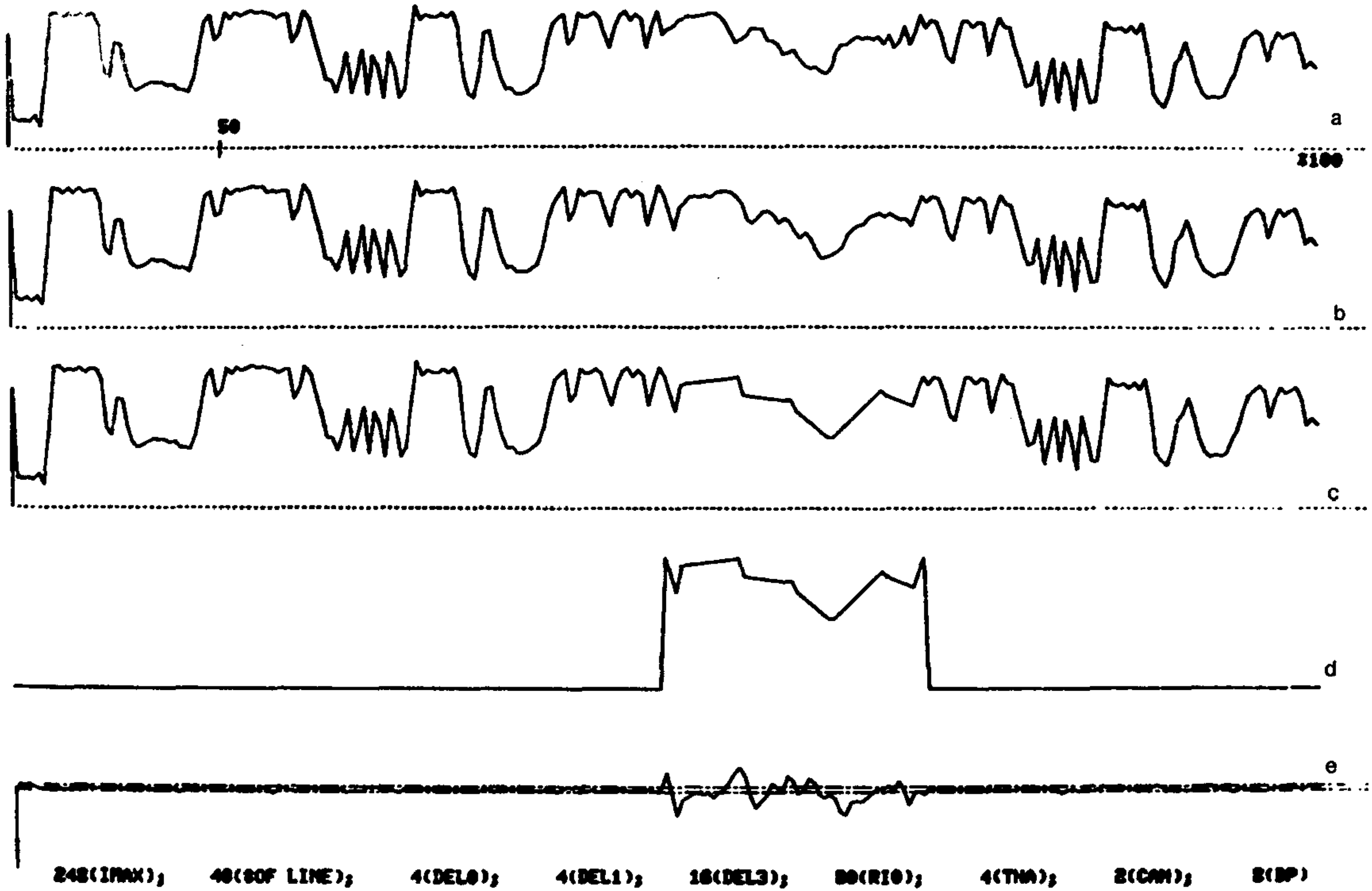

Fig. 5. Moving part encoding.

IV. Encoding breakpoints of straight line approximation.

The straight line approximation of the signal along a line in a moving part is shown in Fig. (6).

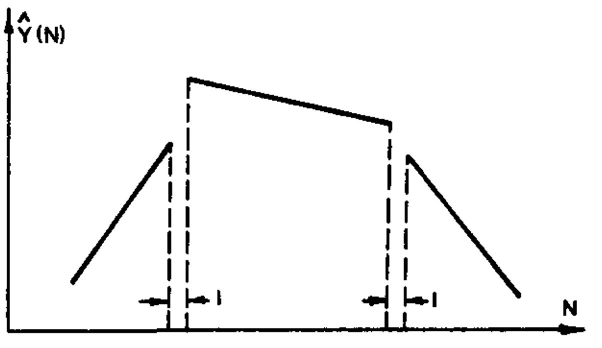

Fig. 6. Straight line approximation of a moving part.

Apparently, for encoding these segments it is sufficient to encode the positions and amplitudes of their breakpoints. The starting point of the first segment is the starting point of this moving part. Similarly, the end point of the last segment is the end point of this moving part. Amplitudes of the starting point and the point of a moving part are nearly the same values of the corresponding points in the previous frame. The difference is approximately a value near the threshold of the moving detector. These difference are not big, and mostly less than the value of the segmenting threshold. So after having determined the positions of these two points, their amplitudes can be estimated by the amplitudes of the corresponding points on the previous frame. In addition, in case they become stationary, these errors will be compensated by the compensating signal.

Therefore it enables us to encode the starting and end points of a moving part only by their positions.

Using this method of segmentation, all breakpoints in a moving part except the starting and end points always appear in pairs. A starting point follows the previous end point immediately. The distance is one sample distance. Hence to indicate the position of a breakpoint pair we only address the starting point. Other than encoding positions, the amplitude of every breakpoint must be encoded individually except the starting and end points of the moving part.

Since there are many dependencies among breakpoints in every field, we use the information of the amplitudes and positions of the breakpoints on the previous line to predict those on the current line. If the predictive error is within some threshold Tp, the breakpoint on the current line is referred to as a matched breakpoint, otherwise unmatched. The matching criterion considers both amplitude and position. As shown in Fig. (7), if

$$\left|\hat{Y}(NAi) - \hat{Y}(NBj)\right| + C\left|NAi - NBj\right| \leq Tp$$

the breakpoint Bj matches Ai, otherwise not, where C is a matching factor chosen according to the picture statistics.

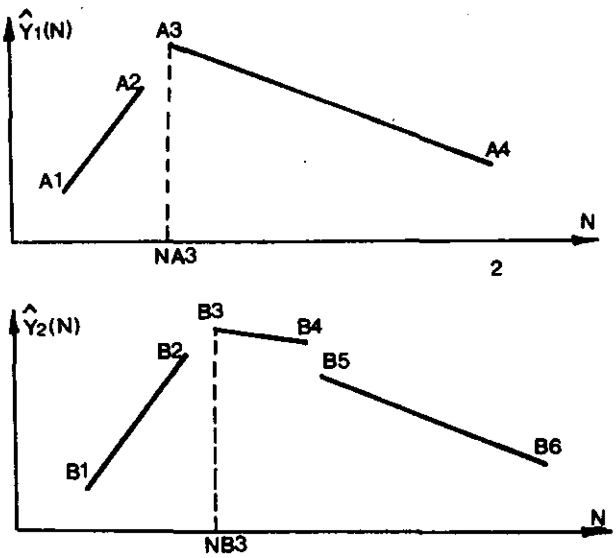

Fig. 7. Matching between two successive lines.

In the matching procedure for every moving part, we consider only the matching state of every starting point of each segment and the end point of the moving part. There are eight kinds of matching states, as shown in Fig. 8.

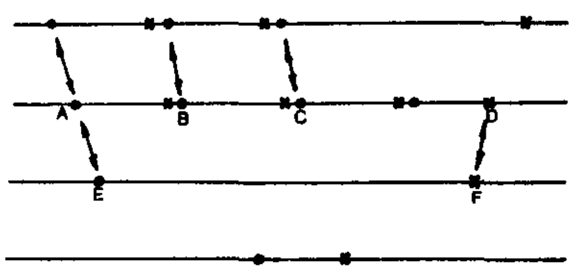

Fig. 8. Matching state of break points.

1) For starting point of segments:

i) Matching relation with the previous line:

a) No reference point on the previous line;

b) Having reference point on the previous line.

ii) Matching relation with the successive line:

a) Being a reference point of a point on the successive line;

b) Not being a reference point of any point on the successive line.

2) For the end points of segments, there are also 4 kinds of matching states similar to the above.

In an encoding procedure, the matching state of every breakpoint(pair) must be indicated. The entropy of this indication information is about 20 percent of the total entropy.

The left picture shown in Fig. 9 is a reconstructed frame processed by this scheme; the right one is the corresponding position distribution of the breakpoints.

Fig. (9). Processed picture and the position distribution of its breakpoints.

V. Compensating signal.

Because sensitivities of the human eye to the errors appearing on a moving part and on a stationary part are not the same, it is not suitable to use only the same criterion on both parts. Either the criterion is suitable for stationary parts but is too low for moving parts or it is suitable for moving parts but is too high for stationary parts. So it is reasonable to use two different criteria to handle this problem.

As a set of significantly changed picture elements from the previous frame, a moving part consists of two kinds of changes. One is moving objects, another is newly uncovered background. By comparing the positions of moving parts in the current frame with the positions of moving parts in the previous frame, the positions of the new background become evident. Thus it enables us to obtain the uncovered background in each frame. The procedure for obtaining a compensating part is shown in Fig. 10.

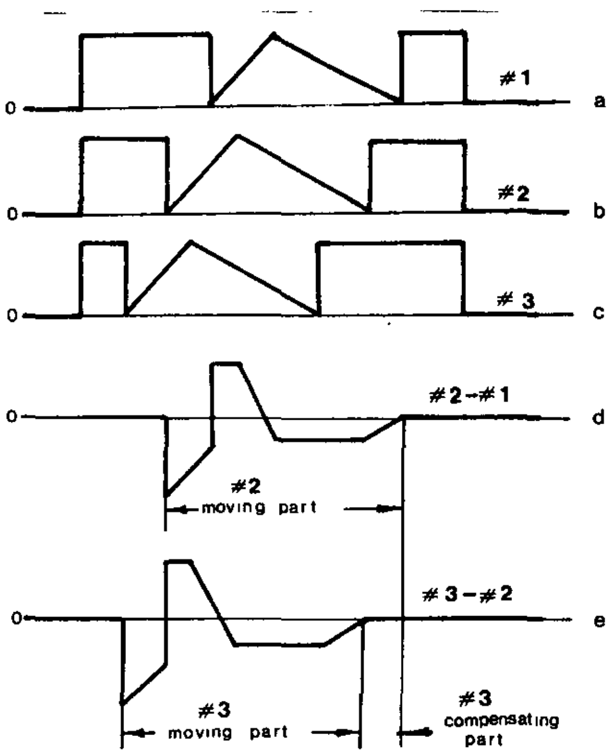

Fig. 10. Procedure for obtaining the compensating part.

It is obvious, that in order to obtain the positions of the compensating parts, positions of moving parts must be saved in a small buffer for the sake of comparision. Therefore it is clear that only amplitude information is sufficient for encoding compensating signal.

In order to recover the resolution of the scene in a compensating part, the compensating signal is added to every picture element along the scanning line on the compensating part. The compensating signal is the quantized signal which is the difference between the original signal in the current frame and the straight line approximation signal in the previous frame.

The difference is caused by two kinds of errors:

1). Errors of straight line approximation--the component of the remainder. Because Kalman filtering generates the least mean square errors, it is likely that larger errors appear at the area where intensity varies rapidly. Since the Kalman filter is adaptive to intensity, larger errors occur mostly in the areas with higher intensity.

2). The quantization errors of starting and end points of the straight line approximation. Because of its nonuniform quantization, larger errors also appear in the area with higher intensity.

The quantization procedure considers the fact that changes in intensity mask the intensity error perception of the human eye [10].

By sending compensating signals, the background is kept very clear even though motion in the picture is rapid.

VI. Information string.

For the sake of convenience we encode the television signal line by line, and send the corresponding information also in accordance with line sequence. Within a line, information of the line can be arranged as the following sequence.

1). The number of moving parts on the encoded line.

2). The information indicating the matching state of every breakpoint (pair) on the line, which is encoded sequentially according to their positions.

3). Sequential information of addresses of the breakpoints on the line.

4). Sequential information of amplitude of every breakpoint.

5). Sequential amplitude information of the compensating signal.

During computer simulation, we calculated the entropies of the above information within each frame. We also calculated what the average code word length of this information would have been within each frame, if it had been encoded by Huffman code. The difference between these two is about 2 percent.

VII. Examples and conclusion

Several sets of television pictures have been processed by computer simulation. One of them is shown in Fig. 11 . It consists of 16 frames (32 fields). In Fig. 11 , only 5 frames are shown.

Fig. 11. Original pictures.

Fig. 12 shows their processed pictures. If near the monitor screen we could find some distortion in moving parts, but hardly find distortion in stationary parts. The bit rate for encoding Fig. 11 is depicted in Fig. 13 for each part of its information.

Fig. 12. Processed pictures.

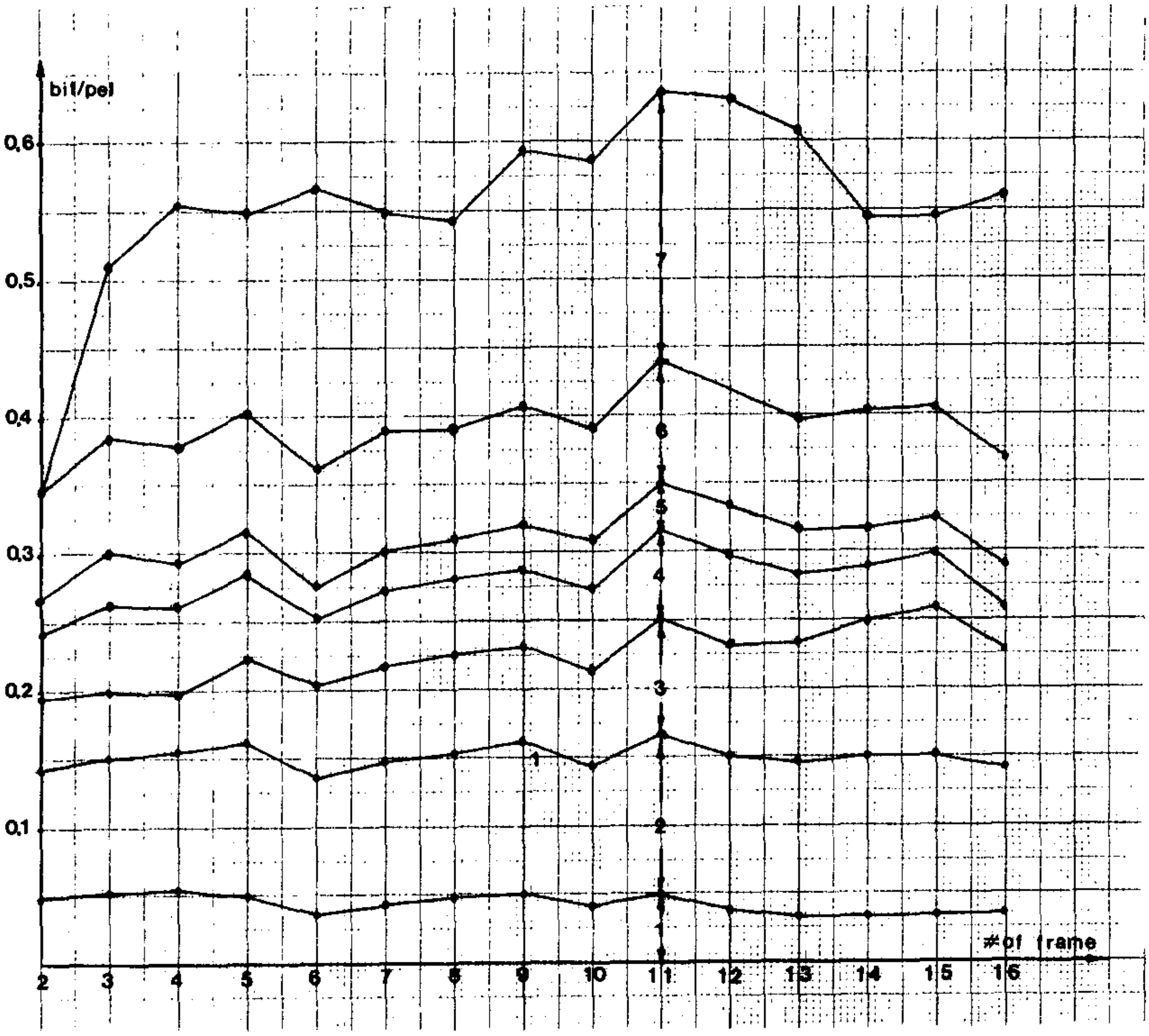

Fig. 13 . Bit rate distributions

1--# of moving parts

2--matched position

3--matched amplitude

4--unmatched position

5--unmatched amplitude

6--matching indication

7--compensating

A comparison of this encoding scheme with conditional replenishment was also made by processing the same pictures. It is concluded that under the requirement of a near same bit rate, the quality of the picture processed by the straight line approximation scheme is superior.

We have not paid much attention to the investigation of human visual psychology. The distortion criteria are still made on some ad hoc basis. We suppose that with correct choice of some distortion criteria, and the use buffer control feedback, better results should be expected.

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