The Detection of Long Error Bursts During Transmission of Video Signals

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In this paper we describe a simple threshold code for monitoring digital communication channels which, with high probability, will detect the presence of an error burst of length at least 70, say, but will ignore shorter bursts. This code has applications to digital systems, such as video-conferencing systems, which have an existing error-correction procedure that can handle small numbers of random errors and bursts of length less than some fixed number, but which are adversely affected by longer bursts.

I. INTRODUCTION

Sophisticated techniques are available for removing redundancy in TV pictures.[1,2] These reduce the cost of transmitting video signals over telephone lines, as, for example, in video-conferencing systems.[3,4] The compressed video signal is represented in digital form and is protected by coding[5] against the most frequently occurring channel errors.[1] Certain other, less common, error patterns, however, are also detrimental to the system, causing the picture to disappear momentarily, a phenomenon that is annoying to the viewer. In this paper we describe a coding scheme that detects a class of error patterns that contributes to this degradation of the system. The scheme can also be used for other digital transmission systems where similar coding procedures are employed.

II. MODEL OF A DIGITAL VIDEO-COMMUNICATION SYSTEM

Figure 1 shows a simplified model of a digital video-communication system, as used, for example, in video-conferencing services.[1-3] This model emphasizes the error-correcting mechanism. Video data (a) from the camera is first passed through a picture coder or data compressor (b) that removes some of the redundancy from the picture.
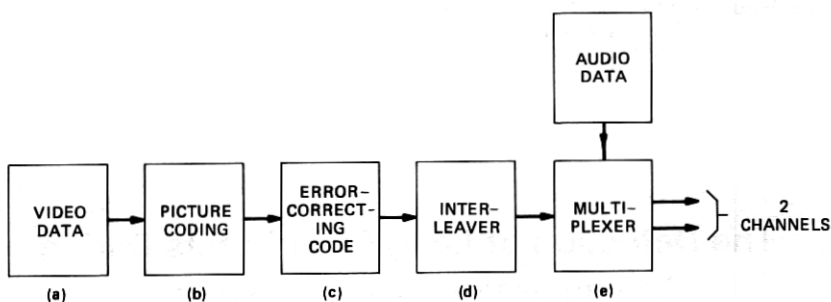
Fig. 1—Error-correcting mechanism in a typical video communication system.

The resulting bit stream is encoded (c) by an error-correcting code, a typical code being the [255, 239, 5] double-error-correcting Bose-Chaudhuri-Hocquenghem (BCH) code.[6] The output from the encoder is interleaved (d), say, to a depth of 35. (This is explained in greater detail below.) Finally, a multiplexer (e) combines the video data from the interleaver with audio and control information, and distributes the result among two high-speed (typically 1.544 Mb/s) channels for transmission. At the receiving end the inverse operations are performed. The audio and control data have a much lower rate than the video data, and can usually be ignored in the analysis of errors. (Other systems use one or even four transmission channels, but it is not difficult to show that our proposed coding scheme applies equally well to these situations.)

To understand how errors on one of the channels affect the picture, we must consider how the interleaver and multiplexer together distribute the bits among the channels. This is explained in Fig. 2. The interleaver consists of an array (b_{ij}) of 35 x 255 bits (Fig. 2a). Code words from the BCH encoder enter the array by rows and are read out by columns. Figure 2b shows the same bits distributed among the two channels. We see that 35 bits now separate any pair of adjacent bits in a code word.

Thus an error burst* of length ≤ 34 on a channel will affect at most one bit from a code word, a burst of length 35 to 69 at most two bits, a burst of length 70 to 104 at most three bits, and so on. If not more than two bits in a code word are in error, this will be corrected by the BCH code. Thus error bursts of length ≤ 69 on any channel are not significant. On the other hand, bursts of length ≥ 70 may cause three or more errors in a code word, and this cannot be corrected by the BCH

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* Definition of burst: Suppose $x_1, \cdots, x_n$ is transmitted and $y_1, \cdots, y_n$ is received. The difference $e_1, \cdots, e_n = y_1 - x_1, y_2 - x_2, \cdots, y_n - x_n$ is the error pattern. If the vector $e_1, \cdots, e_n$ is 0 except for a string of length b, which begins and ends with a 1, we say that a burst of length b has occurred. For example, 00110101000 contains a burst of length 6.
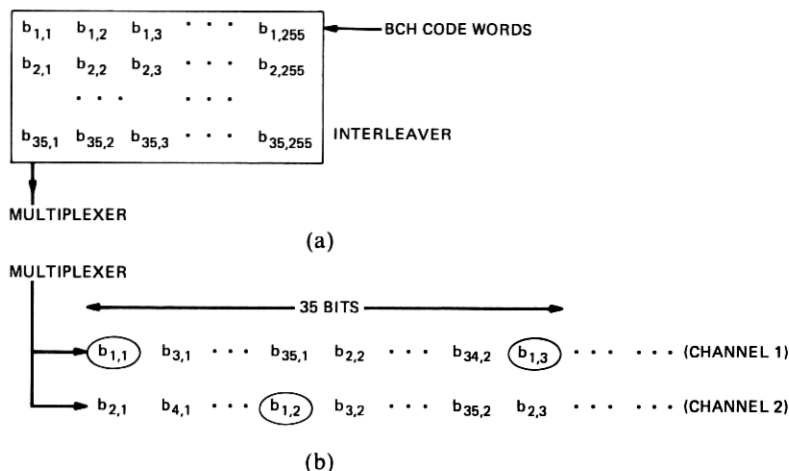
Fig. 2—The interleaver and multiplexer distributing bits among channels. (a) 35 BCH code words are loaded by rows into the array in the interleaver. (b) The same bits after they have been read out of the array by columns and multiplexed between the two channels. Bits from the first row of the array are marked with circles.

code. However, in most cases, the presence of such an error pattern will be "detected," either by the BCH code or by the parity checks associated with the picture coder. When this happens, the receiver normally substitutes the appropriate portion of the previous frame for the missing segment. But if too many errors of this type are detected in one frame, the whole frame must be retransmitted, instead of, for example, just sending the difference from the previous frame. This leaves the screen momentarily blank, which is disturbing to the viewer and is what we are trying to avoid. The penalty for a burst of length greatly exceeding 70 is much higher, for more rows of the array will be affected.

The problem then is to detect whether either channel has suffered from an error burst of length greater than 70. When such a channel has been identified, the appropriate corrective action can be taken (possibly including switching the transmission to a backup channel if the long bursts occur frequently).

The problem is somewhat unusual, since most existing burst detection schemes (compare with Ref. 7) are designed to detect the presence of any burst of length up to some number b_1, while here we are only concerned with detecting bursts of length greater than b_1.

III. BURST DETECTING CODE

The code we propose is a simple threshold scheme, to be used separately on each channel. There are many possible variations of this

code, but we shall just describe the simplest version. The data is usually transmitted down each channel in blocks of some fixed length, say 4200. We wish to detect the presence of an error burst of length ≥ 70, occurring either inside a block or overlapping two adjacent blocks.

3.1 Encoding

Our encoding procedure takes the last 70 bits of the previous block and the 4200 bits of the current block, a total of $4270 = 70 \times 61$ bits, which we denote by

$$u_1, u_2, \cdots, u_{4270},$$

and forms the following check sums:

$$v_1 = u_1 + u_{71} + u_{141} + \cdots + u_{4201},$$

$$v_2 = u_2 + u_{72} + u_{142} + \cdots + u_{4202},$$

$$\cdots$$

$$v_{70} = u_{70} + u_{140} + u_{210} + \cdots + u_{4270},$$

the addition being carried out modulo 2. In other words, the 4270 bits are divided into 61 subblocks of length 70 and the modulo 2 sum $\mathbf{v} = (v_1, \cdots, v_{70})$ of these subblocks is determined, without carries. This check vector $\mathbf{v}$ is then transmitted along with the current block. (Of course, parity checks have been used since the beginning of coding theory, but as far as we know, their use in this particular configuration is new.)

3.2 Decoding

When the bit stream on this channel reaches the receiver, the check sums are recomputed from the same 4270 bits, producing a vector $\mathbf{w} = (w_1, \cdots, w_{70})$, say. The decoder determines the number N of places where $\mathbf{w}$ differs from the received version of $\mathbf{v}$. Of course, if there are no errors, then $\mathbf{w} = \mathbf{v}$ and $N = 0$. The decoder compares N with a fixed threshold θ. If $N \leq \theta$, the decoder decides that the channel is acceptable (and there is only a low probability that a burst of length ≥ 70 has occurred). If $N > \theta$, the decoder decides that there is a significant probability that a burst of length ≥ 70 has occurred, and requests that the appropriate corrective action be taken. The basic configuration of the scheme is illustrated on one channel by the block diagram shown in Fig. 3. A similar arrangement is realized in all four channels (two in each direction). The implementation of this scheme clearly presents no difficulties.
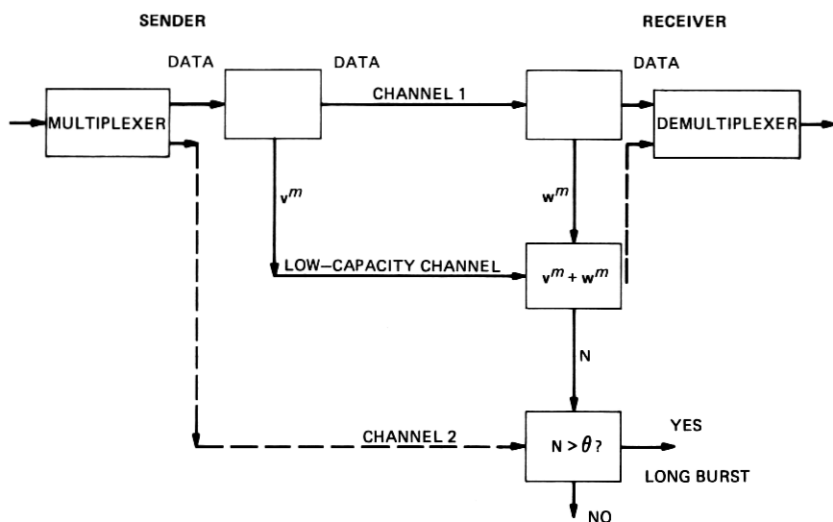
Fig. 3—Simplified block diagram of the proposed scheme for one channel showing the mth data block $\mathbf{w}^m$.

3.3 Choice of Threshold

The following argument shows that an initial threshold of $\theta = 22$ is a good, conservative choice. (However, θ can be left as a variable parameter in the system.) Let us assume that a random burst of errors of length b will begin at any point in the bit stream, and will complement each of the following b bits with probability $1/2$. On the average, $b/2$ bits will be wrong. If b is less than 70, each of the errors will affect just one check bit, and so there will be about $b/2$ places where $v_i \neq w_i$, implying $N \approx b/2$. On the other hand, if $b \geq 70$, all the check bits will be involved, and we can expect $N \approx 35$. However, these are just the average values of N, and the actual values will be different. The variance σ^2 of N is roughly $b/4$, which is 17.5 when $b = 70$. Therefore, an initial threshold of $\theta = 35 - 3\sigma \approx 22$ is recommended. The optimal value can then be determined by experiment. A more precise determination of the threshold cannot be made at this time owing to the uncertainty about the density of 1's inside a burst and of the distribution of burst lengths.

The problem is essentially one of hypothesis testing, of distinguishing between the "null hypothesis" that the channel is acceptable and the hypothesis that a burst of length ≥ 70 has occurred. Let us assume that the burst lengths have an exponential distribution, i.e., that a burst of length $b = 0, 1, 2, \cdots$ occurs with probability

$$c_1 e^{-\lambda b},$$

where λ is a parameter and $c_1 = 1 - e^{-\lambda}$. Then two important quantities associated with our code are the "false alarm" probability, which is

$$\alpha = \text{Prob}(N > \theta \mid \text{channel is good})$$

$$= \sum_{b=\theta+1}^{69} c_1 e^{-\lambda b} \sum_{N=\theta+1}^{b} \binom{b}{N} \frac{1}{2^b}, \tag{1}$$

and the probability of an undetected burst, which is

$$\beta = \text{Prob}(N \leq \theta \mid \text{channel is bad})$$

$$= \sum_{b=70}^{\infty} c_1 e^{-\lambda b} \sum_{N=0}^{\theta} \binom{70}{N} \frac{1}{2^{70}}. \tag{2}$$

If λ is known, these two probabilities can be calculated easily from eqs. (1) and (2) and the best value of θ chosen accordingly. Presumably, β should be made much smaller than α, but this decision must be made by the system designer.

Some possible variations on this scheme follow: (i) **v** could be sent over a separate, slower channel. (ii) The number of check bits, i.e., the length of **v**, could be made greater than 70, thus supplying more information about the state of the channel. [Equations (1) and (2) then need to be slightly modified.] (iii) The decoder could use two thresholds, and declare the channel good if $N < \theta_1$, bad if $N > \theta_2$, and questionable if $\theta_1 \leq N \leq \theta_2$.

IV. SUMMARY

The existing error-detecting procedures for digital communication channels do not distinguish long error bursts from other types of errors, even though in the case of compressed video signals these long bursts contribute to fast retransmissions of the whole frame, leaving the screen momentarily blank, which is annoying to the viewer. We have proposed a simple threshold code that is compatible with the present video-compression and communication-channels systems, and will detect such long bursts with high probability. Formulas are given for the probability of an undetected burst and of a false alarm. The code can be used for monitoring the burstiness of digital communication channels for other services.

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