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Adaptation of Ordering Techniques for Facsimile Pictures with No Single Element Runs

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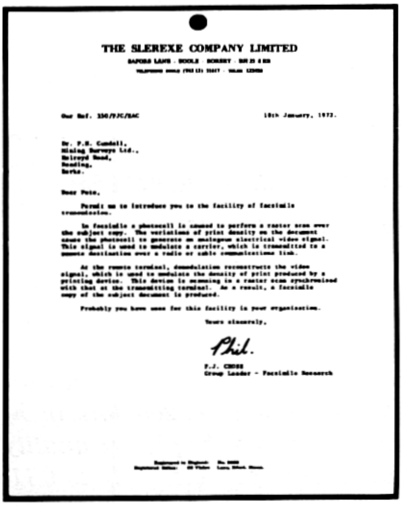
We present a simple strategy for modification of two-level facsimile pictures and adapt our earlier published ordering techniques to take advantage of the modification. Picture modification consists of eliminating all horizontal runs of "black" or "white" elements which are of length one. For pictures with high resolution (e.g., 200 dots/inch), such a modification does not excessively degrade the picture quality. The resulting entropy of the coded pictures is between 0.018 to 0.115 bits/pel for the eight CCITT *pictures, which are scanned and sampled at approximately 200 dots/inch. This amounts to an average reduction of 48 percent compared to one-dimensional run-length coding and 10 percent compared to our previously published best ordering technique.*

I. INTRODUCTION

Coding of two-tone facsimile pictures is gaining considerable importance. Many sophisticated algorithms which use the two-dimensional correlation present in the facsimile pictures have been developed. Most of these code the picture in such a way that an exact reproduction of the picture is possible at the receiver. Considerable bit-rate reduction is possible, however, by approximating the original picture by another picture which can be coded more efficiently than the original. Success of such schemes will depend upon the type of approximation used. Approximations that introduce the least visible distortion in the picture but reduce the bit rate significantly are the most desirable. Problems of picture modification and evaluation of their advantages for two-level facsimile signals have recently begun to receive some attention.[1-5]

We present a simple method of picture modification and then evaluate its advantages with respect to ordering techniques.[6] Pictures are modified so that runs of single "white" (="0") or "black" (="1") elements along a scan line are suppressed. At high resolution of 200 dots/inch, such a modification does not degrade the picture significantly. This preprocessing allows us to modify our earlier published ordering techniques[6–8] in an advantageous way by treating even and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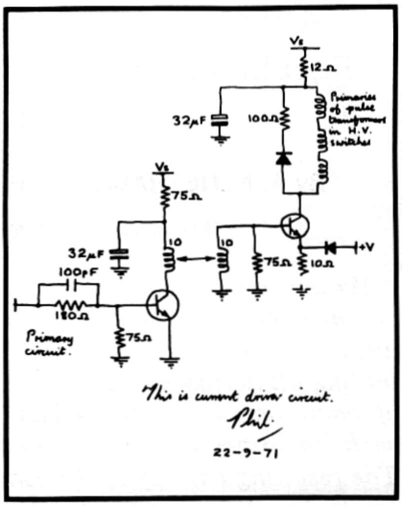

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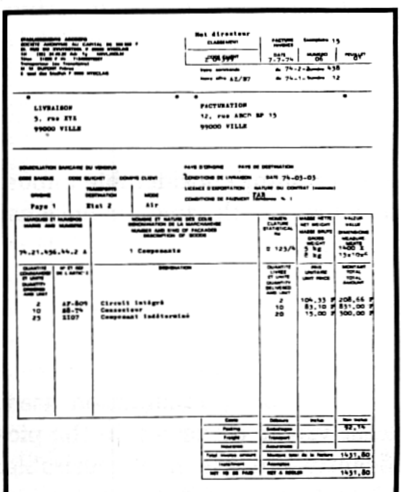
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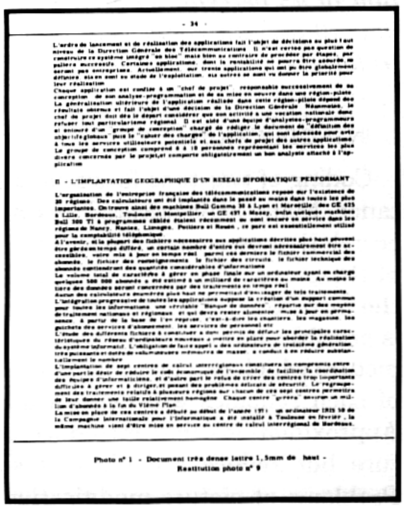
II - L'IMPLANTATION GEOGRAPHIQUE D'UN RESEAU INFORMATIQUE PERFORMANT

Photo n° 1 - Document très dense lettre 1,5mm de haut -
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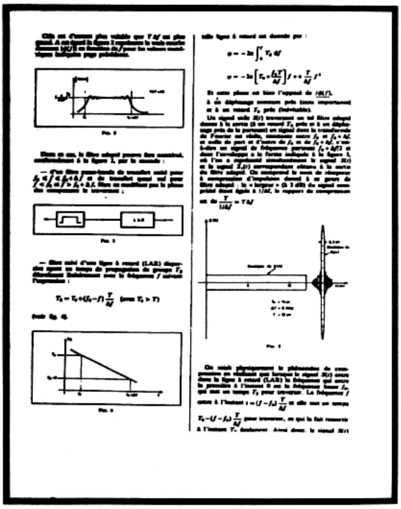
Fig. 1—Original eight CCITT documents. These are scanned and sampled at approximately 200 dots/inch. Each document is approximately $8\frac{1}{2}$ by 11 inches and contains 2128 scan lines, each with 1728 picture elements.

odd samples along a scan line differently. The preprocessing combined with one of our ordering techniques results in entropies for the eight CCITT coded pictures between 0.018 and 0.115 bits/pel. The decrease in entropy due to picture modification is, on the average, 10 percent compared to our previously published best ordering technique.



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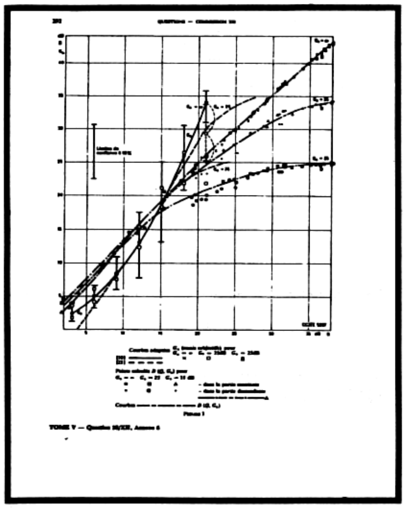

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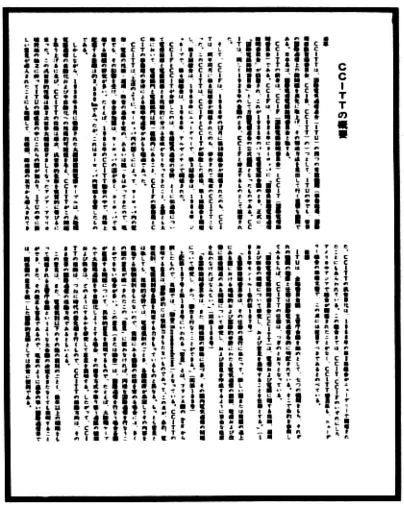

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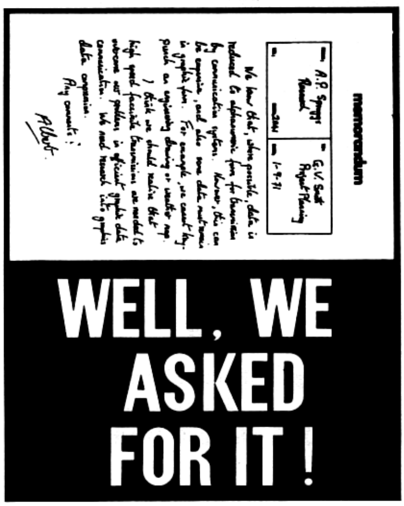

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Fig. 1 *(continued)*

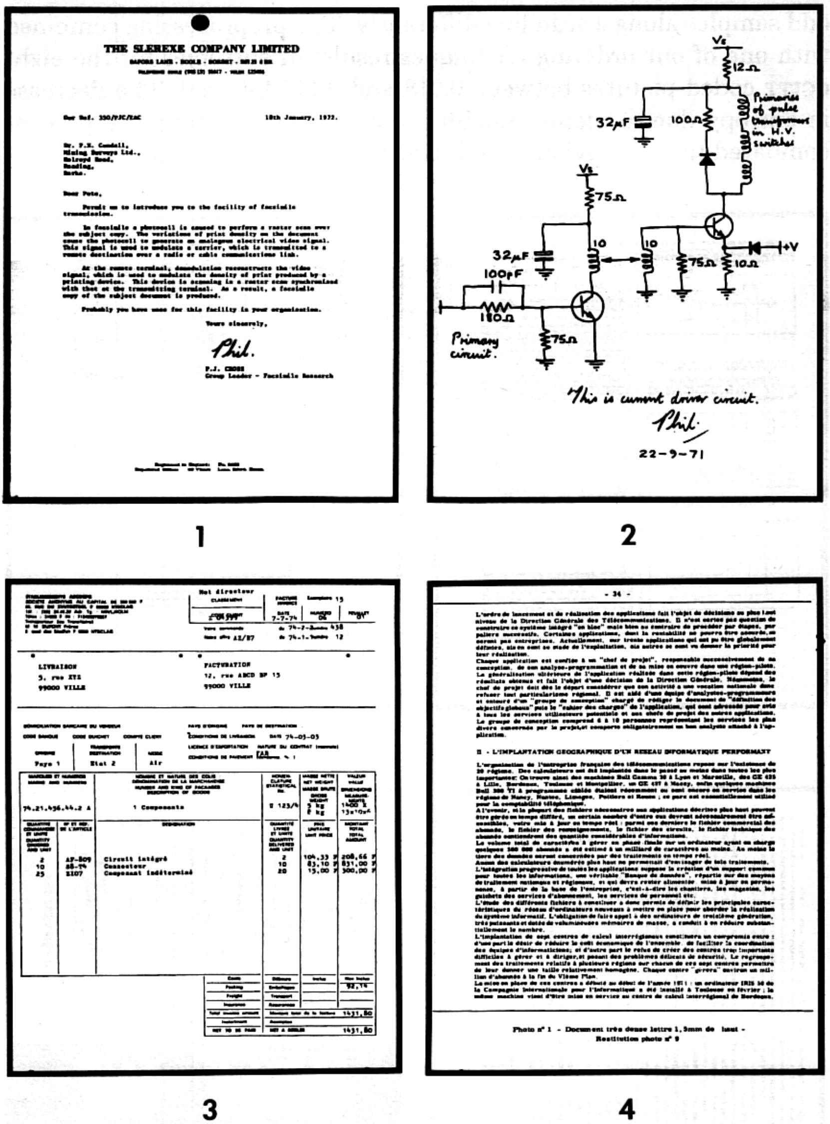
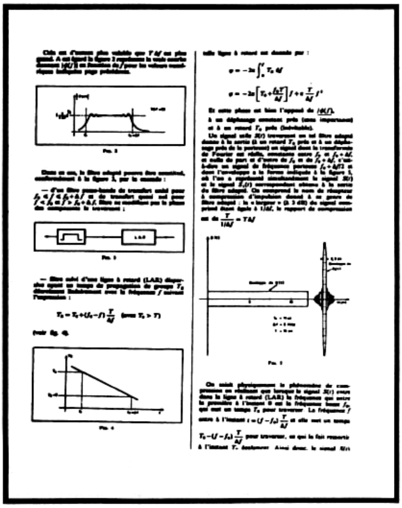


Fig. 2—Modified CCITT documents with suppression of single element runs.

II. ALGORITHM AND SIMULATION RESULTS

In this section we give details of the picture modification strategy, the ordering technique, and the simulation results. More details on the ordering technique can be found in Ref. 8.

As mentioned earlier, we have looked at a simple picture modification strategy. In this strategy, we eliminate all runs of single elements



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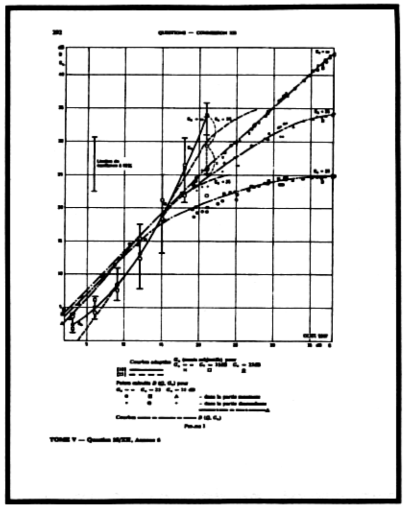

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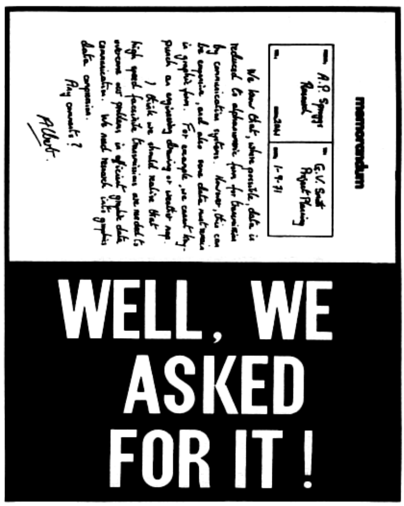

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Fig. 2 *(continued)*

"black" or "white" along a scan line. At a resolution of 200 dots/inch, most of the single runs are due to noise in the digitizing (two-level) process, and these are eliminated, while runs more than one element long are kept intact. Thus, sharpness of the pictures is very rarely reduced. It should be noted that this modification strategy is superior to the one in which a 2:1 horizontal subsampling of the picture material is attempted, since in our case there is virtually no loss of horizontal resolution (except for edges which are one element wide), whereas subsampling entails a definite loss of resolution. Figures 1 and 2 show the results of such preprocessing. Eight original CCITT pictures are shown in Fig. 1, and the modified pictures are shown in Fig. 2. The eight CCITT documents are approximately 8 ½ by 11 inches in size and contain 2128 scan lines with 1728 picture elements (pels) per line. Comparison of pictures in Fig. 1 and Fig. 2 indicates that, for most documents, the distortion due to picture modification is hardly noticeable. There is some distortion, however, as seen in Document 6. In this document, some vertical lines in the graph are broken. This is expected, since any vertical line that is only one pel wide will be removed if the black pel falls on an even sample and is surrounded by odd samples that are white. A slight degradation is seen in some of the other documents (4 and 7) which have small case text material. Whether such a distortion is tolerable or not may depend upon the contents of the document. In any case, it appears that for the majority of the documents the distortion may be tolerable.

Having modified the picture, we now describe adaptation of one of our ordering techniques. Elimination of single runs allows us to process alternate samples differently. As shown in Fig. 3a, even and odd samples are treated differently. Every odd sample is predicted by the previously transmitted pels, as shown in Fig. 3b. Prediction error of the even samples is obtained and used only when necessary. The

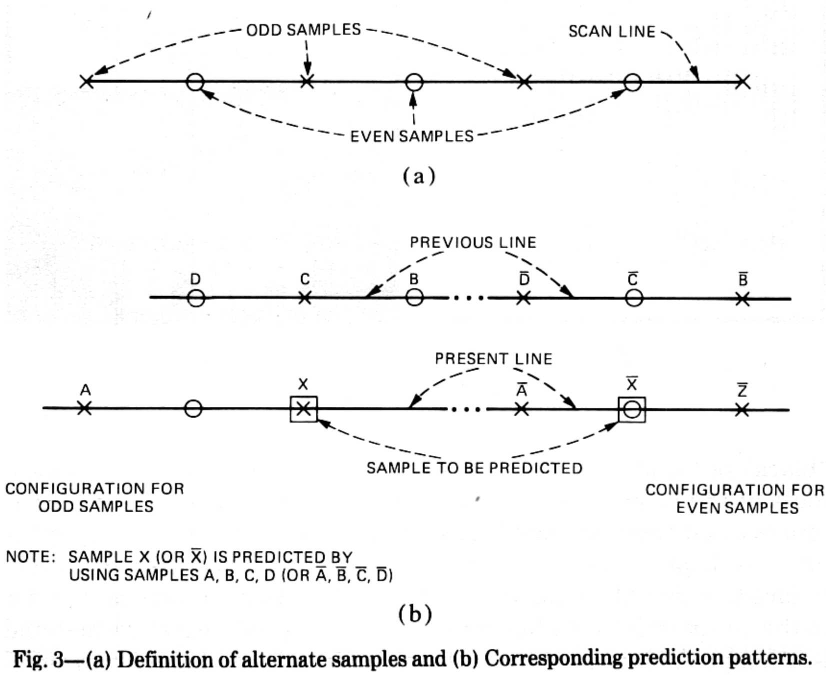

Fig. 3—(a) Definition of alternate samples and (b) Corresponding prediction patterns.

predictor is developed in a standard way as the one which minimizes the probability of making an error if the surround has a given pattern. The pattern used for making the prediction is given in Fig. 3b. More details of the predictor appear in Ref. 8. Since all the single runs have been eliminated by preprocessing, if the two adjacent odd samples are of the same color, the in-between even sample is also of the same color and, therefore, excluded from transmission. Also, in certain other patterns (e.g., 01X0 or 10X1; X = even sample), where the color of the even sample is predictable, its prediction is not transmitted. However, in cases where the color of the adjacent odd samples is different and the color of the in-between even samples is not always predictable, the even sample is predicted by using the pattern shown in Fig. 3b. We note that sample $\bar{Z}$ is not used in the prediction process. Since knowing the color of $\bar{A}$, the color of $\bar{Z}$ is known in all cases where it is required to predict the even samples. In our simulations, we tried predicting even sample, $\bar{X}$, by using the surrounding pattern produced by pels $\bar{A}$, $\bar{B}$, $\bar{C}$, and $\bar{D}$, as well as by only using pel $\bar{C}$. We found very little difference in the results and, therefore, used $\bar{C}$ as the predictor for reasons of simplicity. Having obtained the prediction errors, we now order them. Many variations of the ordering are possible. We describe one of them and mention another. A memory having a number of cells equal to the number of elements in a line (N) is used. As shown in Fig. 4a, if the cells are numbered 1 to N, then the prediction errors corresponding to good states of odd samples are loaded in the memory starting with cell address 1 and increasing sequentially by one; however, the prediction errors corresponding to bad states of odd samples are loaded in the memory starting with the address (N/2) and decreasing sequentially by one. The prediction errors of the required even

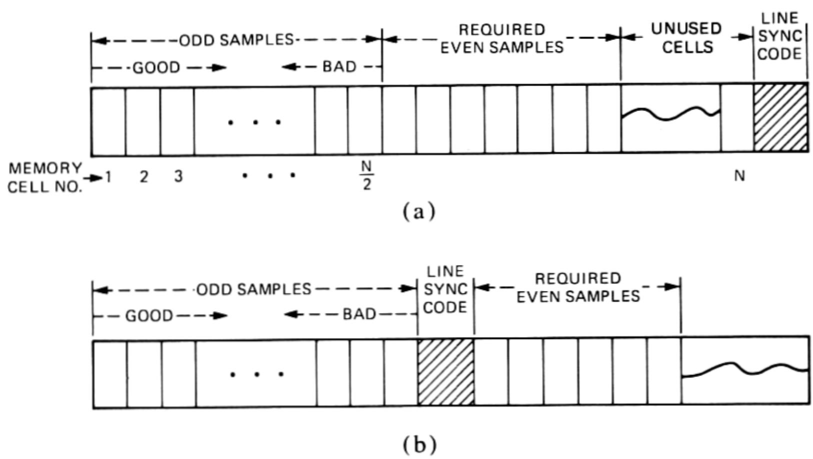

Fig. 4—Two configurations for ordering data from odd and even samples.

samples, on the other hand, are loaded in the memory starting address $(N/2 + 1)$ and increasing sequentially by one. For most of the lines, this line memory containing ordered prediction errors will not be filled, since the required even samples will be less than $(N/2)$. Having ordered the line, we code the run lengths of the contents of the memory, skipping the unfilled memory cells. Here again, many variations are possible. We have used two separate codebooks: one for the run lengths of prediction errors from odd samples and one for the run lengths of prediction errors from even samples. The run is broken at $N/2$, i.e., the boundary between the even and odd samples. This does not allow us to drop any runs of odd samples. To drop the first run in the good region of the odd samples, an alternative arrangement, shown in Fig. 4b, is used. Here the line sync is transmitted between the coded data from the even and odd samples of a line. Dropping the first run is possible since the same code is used for the good and bad region of the odd samples and since the number of encoded odd samples in a line is fixed $(=N/2)$. If it is desired to use three sets of codes (one for the good region of the odd samples, one for the bad region of the odd samples, and one for the required even samples), then the first run of the odd samples cannot be dropped. However, we can still use our previously published extensions of ordering techniques[8] such as bridging, dropping last decodable run for the data from odd samples, since the boundary between the data from the odd and even samples is clearly defined by the line sync code. Here again, we skip the unfilled memory cells of the even samples. Although these extensions would make the algorithm more efficient, we did not simulate them.

Table I shows the simulation results for the eight CCITT pictures. We show results of three other schemes (taken from Ref. 8) for the purposes of comparison. For each scheme and each picture, we compute statistics of run lengths of "zeros" (no prediction errors) and "ones" (prediction errors) and then calculate entropy in bits/pel. The predictor is optimized for each individual picture. It is seen from this table that the ordering techniques with picture modification (row 4) result in entropies which are between 0.018 to 0.115 bits/pel. Compared to one-dimensional run-length coding, these entropies are less by 48 percent on the average. Also, comparing with one of our best ordering techniques (from Ref. 8), the reduction in entropy is 10 percent on the average. We note that many extensions of ordering techniques which were used to generate entropy numbers of row 3, Table I, can be used along with picture modification for further reduction in bit rate.

III. CONCLUSIONS

The picture modification strategy described in this paper is rather simple, easy to implement, and does not result in excessive degradation

Table I—Entropy results for the eight CCITT documents. Note that the entropy numbers do not include certain bits required for housekeeping (line sync, color of the beginning run of each line, etc.) and the predictor is optimized for each picture.

No.	Coding Algorithm	Entropy (bits/pel) CCITT Image Number							
		1	2	3	4	5	6	7	8
1	One-dimensional run-length coding	0.0505	0.0447	0.0914	0.1652	0.0988	0.0679	0.1791	0.0870
2	Run-length coding of prediction errors	0.0466	0.0373	0.0693	0.1640	0.0795	0.0482	0.1678	0.0678
3	Run-length coding of ordered prediction errors with two sets of codes for good and bad region, bridging of good-bad boundary, last decodable run dropped	0.0324	0.0210	0.0506	0.1239	0.0569	0.0312	0.1250	0.0398
4	Ordering techniques with picture modification (single element runs eliminated)	0.0294	0.0183	0.0441	0.1130	0.0505	0.0309	0.1153	0.0351

of the pictures. Our previously described ordering techniques can be modified to reduce the bit rates. The new technique gives bit rates between 0.018 to 0.115 bits/pel. This is about 48 percent less than bit rates obtained by simple one-dimensional run-length coding.

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