AN INTERLEAVING TECHNIQUE FOR BLOCK CODING OF BLACK-AND-WHITE FACSIMILE DATA

D. Weifang Doong, Huizhu Lu, G.E. Hedrick

Oklahoma State University
Dept. of Computer Science

ABSTRACT

A new method of one-dimensional compression, called Interleaved Block Coding (IBC), is presented. It features a fixed-rate output exhibiting a strong noise immunity. The coding method works well irrespective of whether the image is largely-white or largely-black; and the fixed-rate output exhibits a strong immunity to transmission errors. The method also encodes block-pairs of binary image data without the need for codebooks. By providing a sufficient coding field, a lossless form of coding is possible. For better noise immunity, a lossy form of coding is preferred with encoding distortion taking the form of lost black elements. In the case of distortion, a copy procedure based on the color correlation between two connected pixels has been found to be effective for reducing the level of black element loss. Also, the results of simulation for 8-pixel blocks showed a high degree of intelligibility being maintained in the decoded image after exposure to random transmission errors whose average rate may be as high as one in 32 bits.

INTRODUCTION

For efficient coding, there are always two fundamental concepts involved in converting information stored on paper to a bit-mapped electronic format. One is image-data compression, which reduces the amount of redundant data required either to transmit or to store an image. The other concept is immunity to transmission errors, which always are caused by channel noise. A large number of efficient coding methods for black-white images have been proposed and studied [1-5]. Most methods, which can achieve higher compression ratios, feature variable-rate output at the encoder and inevitably require variable-velocity scanners for synchronous transmission over digital channels. One penalty for those efficient source codings is an increased sensitivity to errors in the transmission channel: a single received bit error will corrupt the remainder of the image when resynchronization sequences are not incorporated into the coded data stream. Consequently, these compression systems require high quality channels for successful image transmission. Most compression schemes also require codebooks to encode and decode data. For some types of channels, noise immunity has priority over compression yield. Examples include HF data links, aircraft communication channels and low-grade telephone circuits. The compression method presented in this paper yields intelligible images under quite noisy transmission conditions. The constant output bit rate provides for a simple interface with fixed-rate equipment. The system is suitable where low implementation complexity has priority over high compression yields. The system, by virtue of being constant-rate, does not require continuous codeword synchronization, a necessity for variable-rate systems. In addition to providing strong immunization from transmission errors, the coding method encodes block-pairs of binary image data over a field of blocks without the need for codebooks.

INTERLEAVED BLOCK CODING SCHEME

In a typical two-tone image, most part of the image is white, the amount of black is usually a very small fraction of the total area of the image. Therefore, it appears that rearranging the black element content to occupy the white spaces reduces the number of bits to be transmitted. A scheme based on this idea is described now. This scheme is similar to the WBS (white block skipping) [6] in some ways. For the WBS, the white space is skipped and only the black is transmitted; for the IBC (Interleaved Block Coding), the black element content is rearranged to occupy the white spaces. Each scan line is divided into pairs of N-bit blocks and for each block-pair a fixed-length codeword is transmitted consisting of a three-bit header followed by an N-bit block pattern. An image is restored from a coding field which is comprised of a fixed number of block-pairs.

Definition of Block-Pair States

Based on the presence of the all-white, all-black and nonwhite block pattern on the left or right side of a block-pair, each block-pair is classified as being in one of nine states (Table I).

TABLE 1. DEFINITION OF BLOCK-PAIR STATES AND HEADER WORD

Block-Pair Pattern	Block-Pairs State	Header Word
white-white	WW	000
black-white	BW	101
nonwhite-white	NW	100
white-black	WB	011
white-nonwhite	WN	010
nonwhite-nonwhite	NN	001
nonwhite-black	NB	111
black-nonwhite	BN	110
black-black	BB	111

For data-compression, only combinations of three header coding bits identify these nine states. Instead of increasing the header wordlength to four bits to identify the ninth state (**BB**), header word 111 is chosen to represent the nonwhite-black (**NB**) and the black-black (**BB**) block-pair states. The fact is that the combinations of header (111) and adjoined block patterns (all 1s) will never occur in the other eight-state arrangement. The nine states' header codings are shown in Table 1.

Coding Procedure

The coding procedure consists of two stages. (A) Scanning for the block-pairs of the coding field for the presence of the **NN** (nonwhite-nonwhite) block-pairs. The scan starts from the leftmost proceeding to the rightmost block-pair of the field. When an **NN** block-pair is detected, its right nonwhite block pattern is stored into a first-in first-out (FIFO) buffer. (B) Encoding block-pairs. The encoding stage commences after the scan stage is completed. From the leftmost block-pair of the field, each block-pair is encoded. A three-bit header word is assigned to be the state identification of each block-pair. This header is followed by an N-bit block pattern, where N is the number of pixels assumed to be in the block. The N-bit block pattern depends upon the state of the block-pair. For the block-pair of a **NW**, **WN**, **NB** or a **BN** state, the N-bit block pattern is the nonwhite block of the pair. For the black-black (**BB**) state, the all-black left block pattern is transmitted. If the state of the block-pair is **NN**, since the right nonwhite block is fed into buffer the left nonwhite pattern is the only choice. Finally, if the current block-pair exhibits an all-white (**WW**), black-white (**BW**) or white-black (**WB**) pattern, the transmitted block pattern is taken from the FIFO buffer. If the buffer is empty an all-white pattern is transmitted. In this coding method, right nonwhite elements of **NN** block-pairs in the field are carried out by the **WW**, **BW** and **WB** block-pairs. An example is shown in Fig. 1.

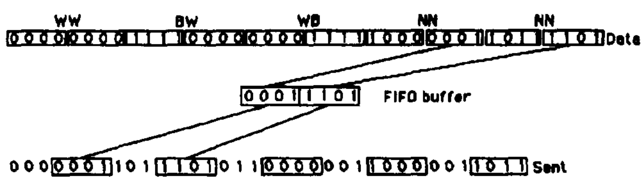


Figure 1. Example of **IBC** Coding Procedure, 4-bit Block

Decoding Procedure

At the receiver a reverse two-stage process is implemented. (A) Examining the input header words for **WW**, **BW** and **WB** states. At the receiver, when a **WW**, **BW** or a **WB** state is examined the adjoined N-bit block pattern is fed into a FIFO buffer. (B) Decoding block-pairs. At the end of a scan for a field, the decoding stage starts. Here the block-pair pattern is reconstructed according to the header word and its adjoined block pattern. For a **WN** or an **NW** block-pair, an all white N-bit block is reinserted into left or right block. If a block-pair identifies the **BN** state, then an all-black N-bit block is inserted into the left block. **NB** and **BB** block-pairs have the same header (111); both states transmit the left block pattern, so the all-black block is reinserted into the right block. If the block-pair is the **WW** state, then two N-bit blocks for all-white are restored. For the **BW** and the **WB** states, the all-black and the all-white blocks are inserted into suitable positions. For an NN block-pair the right nonwhite elements are taken from the FIFO buffer. An example is given in Figure 2.

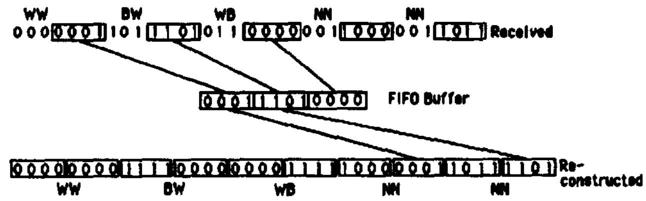


Figure 2. Example of **IBC** Decoding Procedure, 4-bit Block

Coding Diagram

In view of the interleaving nature of the compression technique, the method has been designated "Interleaved Block Coding" (**IBC**). Figure 3 contains the block diagram for instrumentation of this compression system. In the encoder the auxiliary FIFO buffer store holds the right nonwhite elements of all **NN** block-pairs in the field. The main buffer store implements the field delay. At the end of an encoded field the FIFO contents are inserted into the output, via S2, when **WW**, **BW** and **WB** patterns are detected. For each block-pair the header and block pattern are adjoined and released serially into the transmission channel. At the receiver, the header and block pattern components of the codeword are separated and for **WW**, **BW** and **WB** states the block pattern is fed into the FIFO buffer. At the end of a decoded field the contents of the later are reinserted into the NN block-pairs as identified by the delayed header words, and the reconstructed block-pair is fed to the recording unit serially.

Encoding Distortion

One impediment to the use of this algorithm is the occurrence of the total number of NN block-pairs is over the total number of **WW**, **BW** and **WB** block-pairs, preventing the complete transmission of the contents of the FIFO buffer at the end of the field. This is called field "overflow"; the simplest strategy is not to transmit nonwhite blocks, their original right nonwhite blocks are replaced by the all-white pattern at the receiver. This process is termed "blanking" of excess nonwhite blocks. The resulting distortion takes the form of lost black elements. In a later section there are some techniques to improve this case where surplus nonwhite blocks are blanked and encoding distortion consists entirely of lost black elements.

Compression Ratio

The basic compression ratio, that can be obtained, with the Interleaved Block Coding method readily is seen to be:

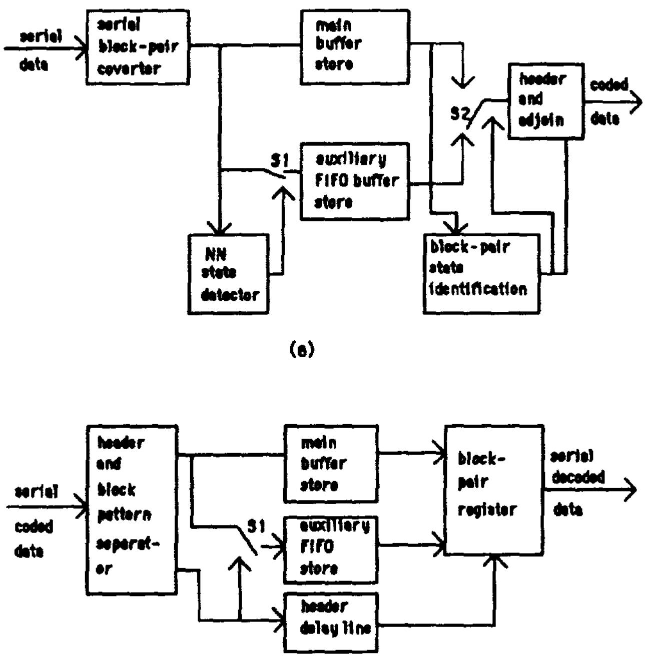
$$CR = \frac{2N}{N + 3} \quad (1)$$

$$= \frac{2}{1 + 3/N}. \quad (2)$$

Where N is the number of pixels in each block. The bit rate per block is defined as the reciprocal of the compression ratio. The result as a function of N is plotted in Figure 4. The compression ratio tends to two when the block size grows to infinity. However, beyond a value of N of about 8 pixels the compression ratio increases only gradually for increasing. The compression ratio of the **IBC** is not very high, but in many instances the sacrifice in compression provides for ease of implementation decreasing the complexity of the system. In the next section a block size of 8 pixels is used throughout the simulation. It is a good choice in terms of performance and efficiency of implementation allowing use of commercial digital ICs and eight-bit microprocessors.

SIMULATION STUDIES

This section shows the performance of the IBC using simulations with eight test images. The set of test images is shown in Figures 5 and 6. The original documents are all 8 1/2 x 11 in size generally corresponding to the set of eight CCITT reference documents. The sampling rate is 150 ppi. For the block size, we choose an 8-bit block throughout the simulation therefore the compression ratio is fixed at 1.45, which corresponds to a bit rate of 0.69 (defined as the reciprocal of the compression ratio).



(b)

Figure 3. Interleaved Block Coding Scheme
(a) Coding Diagram (b) Decoding Diagram

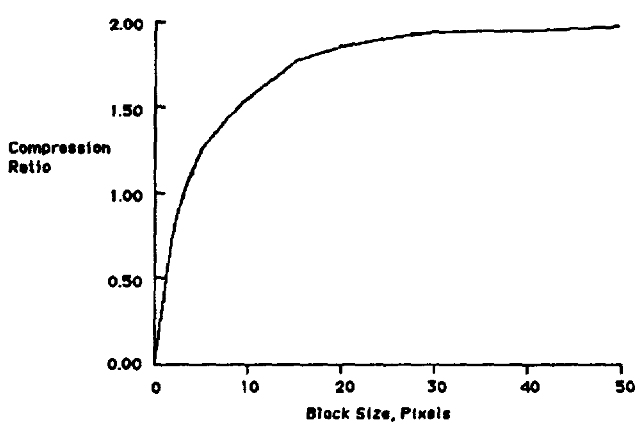


Figure 4. IBC Compression Ratio as a Function of Block Size

Interleaved Block Coding Method

The measured probabilities of the block-pair states for the test images are shown in Table 2. From Table 2, it is clear that overflow-free, or lossless, coding is obtainable for all the test images when the field size is sufficiently large such as the whole image (15360 block-pairs). The size of the whole image as a test field produces the probability $P_{(WW+WB+BW)}$ which is sufficiently larger than the probability P_{NN}. In a practical implementation it is desirable to keep the field size as small as possible. Apart from increased amount of storage and hardware, an important reason is the effect of transmission errors. From the simulation results for Interleaved Block Coding in field size F=160 (160 block-pairs), the reconstructed images are good, especially when an image contains large white or large black spaces (such as A2, A6 and A8). This is due to the number of WW, BW and WB block-pairs in the coding field being enough to transmit the NN block-pairs. The subjective effect of blanking of blocks in overflow fields may be examined in Fig. 7 where the image A4, is densely typed in English text. Inter-word and inter-letter white spaces of dense text are obviously by themselves unable to furnish enough WW, BW and WB pairs of blocks to convey the abundant right blocks of nonwhite-nonwhite block-pairs in the field. However, it is evident, that the intelligibility of characters is mainly unaffected by this kind of distortion. This is due to the fact that in the event of blanking, NN pairs will always have only the right block deleted, with the left block intact, and for a series of such NN block-pairs in an active region, left nonwhite blocks remain which are sufficient to preserve the form and legibility of characters if the block size is not very large. Thus, even in the worst situation, when all the NN block-pairs in the field have their right blocks deleted, intelligibility largely is preserved due to retention of left nonwhite blocks. Generally, the loss of blocks is quite visible even though the percentage of such losses over the total number of blocks in the image may be very small. The human eye is quite sensitive to loss of black elements in the image. A modified IBC technique improves this coding method.

TABLE 2. STATISTICS OF TEST IMAGE FOR BLOCK SIZE OF 8 PIXELS

	P_{WW}	P_{WB}	P_{WN}	P_{BW}	P_{NW}	P_{NN}	P_{NB}	P_{BN}	P_{BB}
Image A1	.632	.015	.092	.003	.073	.132	.024	.015	.014
Image A2	.772	.024	.054	.002	.058	.042	.008	.010	.030
Image A3	.775	.018	.045	.001	.034	.074	.014	.012	.026
Image A4	.645	.015	.050	.001	.066	.169	.024	.014	.016
Image A5	.742	.023	.045	.001	.064	.094	.007	.008	.016
Image A6	.713	.023	.101	.000	.085	.045	.004	.003	.027
Image A7	.430	.031	.140	.004	.141	.136	.059	.043	.015
Image A8	.397	.008	.066	.003	.067	.094	.042	.031	.292

Modified Interleaved Block Coding Method

In order to reduce the amount of encoding distortion, a simple strategy may be adopted. Instead of omitting the last-occurring nonwhite blocks of the field, we use the color correlation of pixels in a block-pair source to reconstruct the image; i.e, for two side-by-side pixels, the latter is always the same color as the former. The procedure is as follows. In the first step of the coding procedure, when an NN block-pair is detected, its even numbered pixels (2, 4, 6, 8, 10, 12, 14, 16 pixels in the simulation) are extracted as an N-bit block pattern and stored into the FIFO buffer. For the encoding step for an NN block-pair state, the odd numbered pixels are the only choice as a transmitted block pattern since the even numbered pixels have been fed into the buffer. There is no change any other state, either in the coding procedure or in the decoding procedure. At the end of the decoding step for an **NN** block-pair, the algorithm restores the odd numbered-pixel block pattern which is transmitted by the pair itself, and restores the even numbered-pixel block pattern which is taken from the FIFO buffer according to their original odd or even numbers. The procedures of the modified **IBC** described above occur with the non-overflow condition. When the overflow condition happens, the even numbered-pixel block patterns in the FIFO buffer are not all transmitted by **WW**, **BW** and **WB** block-pairs, thus some NN block-pairs will only have the odd numbered-pixel block pattern left at the end of the decoding procedure. Instead of substituting by the all-white pattern at the receiver to lose black elements, we simply make a copy of the odd numbered-pixel block pattern as the even numbered-pixel block pattern, then reinsert these two patterns which have odd numbered and even numbered pixels respectively into their original positions. Figure 8 shows an example of modified **IBC** under overflow condition.

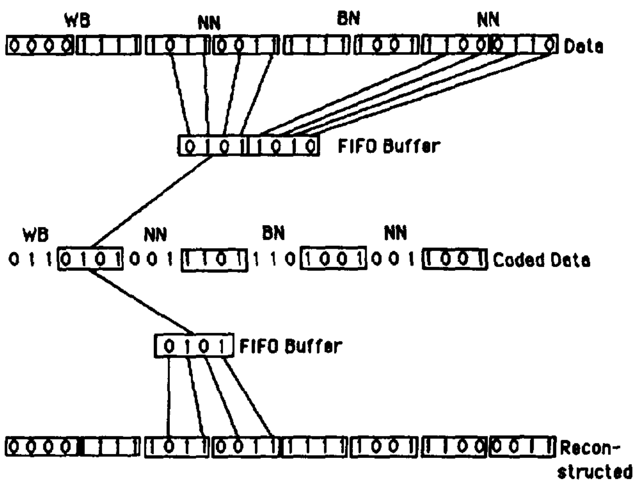


Figure 8. Example of Modified IBC, 4-bit Block, Overflow

The simulation results of the modified **IBC** with a field size, F=64 ,are represented in Figure 9. Comparing these with the results for the **IBC**, the improvement in the distortionless transmission is significant. This is expected because instead of blanking the blocks, we take advantage of color correlation between two connected pixels within a document by duplicating the pixels. The modified **IBC** scheme exhibits a large improvement in distortionless transmission, and it is still a simple, efficient coding method.

EFFECTS OF TRANSMISSION ERRORS

IBC and Modified IBC Techniques

The performance of the IBC and the modified IBC methods has hitherto been described using the assumption of error-free transmission conditions. In the event of transmission errors the effect depends on which type of bits have been corrupted. If the bits of the block pattern are incorrectly received, then the reconstructed pattern shows the errors on a pixel-by-pixel basis; i.e., a single corrupted bit produces a single reconstructed pixel error. The facsimile image can tolerate a substantial number of this type of errors without loss of intelligibility, especially if they are sufficiently isolated from one another. If the bits of the header word are incorrectly received, the corruptness of the reconstructed image is more serious. A false report on the status of the current block-pair is the direct result. The most serious effect occurs when an NN, **WW**, **BW** or a **WB** state header word is corrupted or generated. Then an incorrect block will be placed in the FIFO buffer, or a valid block may be omitted. Because the reinstatement of the FIFO buffer contents works on a sequential basis, the result can be the incorrect placement of all the blocks in the buffer. However, there is no total failure of the decoding process. **WW**, **BW**, **NW**, **WB**, **WN**, **NB**, **BN** and **BB** block-pairs may still be correctly reinserted. The left halves of nonwhite-nonwhite (NN) block-pairs will also be recovered without error for uncorrupted **NN** header states in the field. This aspect is of importance as it ensures that a large proportion of the image material is successfully reconstructed even if the sequential reinstatement of right blocks of nonwhite-nonwhite pairs has been affected adversely. Furthermore, since the proportion of header bits in the coded bit stream is small, consequently the **IBC** system is able to withstand relatively large levels of transmission errors.

The effects of transmission errors were investigated via simulation by subjecting the coded output of the image A1 to controlled amounts of computer-generated random errors. Figure 10 show the reconstructed images for average error rates of 1 in 1000, 1 in 100 and 1 in 32, by using the modified **IBC** respectively. From experimental results, an excellent level of intelligibility is preserved at the rate of 1 in 1000. At the rate of 1 in 100 the text is readable completely and its intelligibility is largely unimpaired. When the average error rate is increased to 1 in 32 the quality is degraded to some extent, but it is still possible to read and understand the text. Certain individual characters are unrecognizable but words and sentences can be deciphered from context.

Comparison with White Block Skipping Method

As mentioned in an earlier section, the compression ratio of the **IBC** is low. Table 3 shows a comparison of the compression ratio achievable by the **IBC** compared to the original white block skipping (**WBS**) technique. In structured images such as vertical densely-typed text, e.g., Chinese and Japanese and largely-black documents, both methods achieve nearly ideal compression ratios. When a document contains large black portions such as A8, the **IBC** even has a slightly higher compression ratio than the **WBS**. However, it appears that for typical documents, the **WBS** is superior to the **IBC** in data compression.

One penalty for efficient coding is an increased sensitivity to channel errors. Figure 11 gives clear results of the effects of transmission errors for higher compression ratio techniques at a variable-rate output. For the **WBS** method, at the error rate of 1 in 1000, some words are recognizable, but sentences and context obviously cannot be read from those words. At the rates of 1 in 100 and 1 in 32, the entire image is corrupt and the text totally is unreadable. When transmission errors occur, a higher compression ratio makes the reconstructed image worse. The **WBS** works especially well in data compression for largely-white images such as A2 and A3. A bit for all white block changing from 0 to 1 can cause loss of synchronization. Such an error causes the receiver to expect the wrong block pattern for the following block. As a result, the block pattern is reconstructed and located incorrectly; the error propagates to the subsequent blocks. Compared to the **WBS**, the **IBC** has a lower compression ratio, but a higher image quality when channel noise occurs. The fixed-rate output coding technique proves to have strong immunity to transmission errors at least for single bit flips.

TABLE 3. COMPRESSION RATIOS OF IBC AND WBS FOR 8-BIT BLOCK SIZE

A1	A2	A3	A4	A5	A6	A7	A8	Aver
				WBS				
2.28	3.19	3.14	2.23	2.86	2.85	1.64	1.44	2.45
				IBC				
1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45

CONCLUSIONS

A fixed-rate one-dimensional compression method in which the input image data is delayed and pairs of blocks are encoded in accordance with their white states has been presented. The constant-rate output provides a strong immunity to transmission errors and without requiring continuous codeword synchronization as is necessary in variable-rate systems. Also the method encodes block-pairs of two-tone image data without the need for codebooks. In the case where distortion is due entirely to the blanking of blocks, a copy procedure based on the color correlation between two connected pixels has been found to be an effective method for reducing the level of black element loss. The results of simulation by using 8-pixel blocks have shown images with a high intelligibility. In the presence of a transmission error rate of 1 in 100 bits, the reconstructed image maintains a good intelligibility; at a rate as high as 1 in 32 bits the recovered image largely is readable.

REFERENCES

[1] T. S. Huang, "Coding of Two-Tone Images," *IEEE Trans.on Commun.* COM-25, no.11, pp. 1406-1424, Nov. 1977.

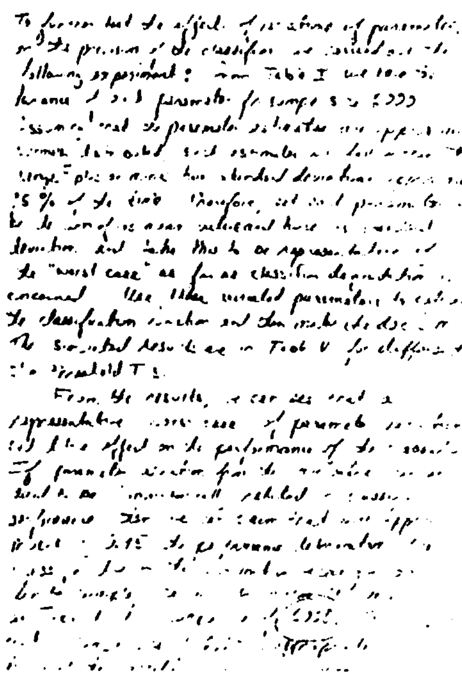
[2] Y. Yasuda, "Overview of Digital Facsimile Coding Technique in Japan," *Proc. IEEE* Vol.68, no.7, pp. 830-845, July 1980.

[3] R. Hunter & A. H. Robinson, "International Digital Facsimile Coding Standards," *Proc. IEEE*, Vol.68, no.7, pp. 854-867, July 1980.

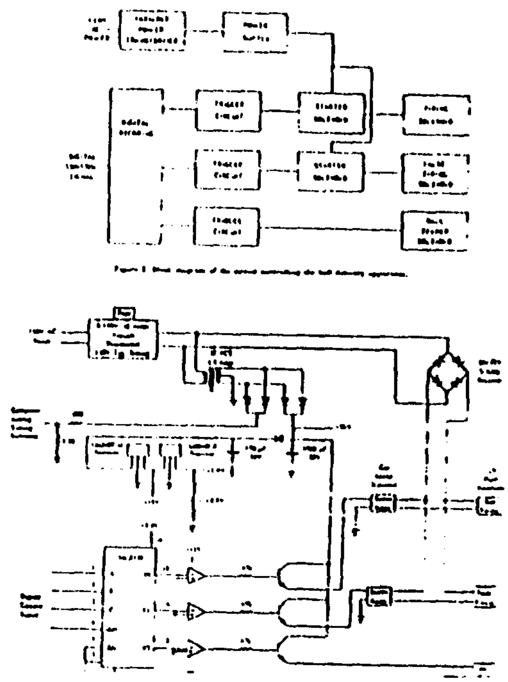
[4] R. B. Arps, "Bibliography on Binary Image Compression," *Proc. IEEE*, Vol.68, no.7, pp. 922-924, July 1980.

[5] H. S. Hou, "Digital Document Processing," pp. 116-139, New York, John Wiley and Sons, 1983.

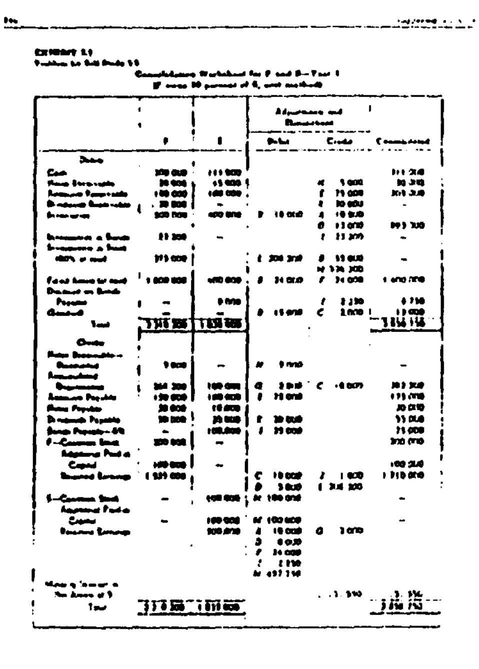
[6] F. Coulon, and M. Kunt, "An Alternative to Runlength Coding for Black-and-White Facsimile," *Proc. 1974 International Zurich Seminar on Digital Communications*, Zurich, Switzerland, pp. C4.1-C4.4, March 1974.



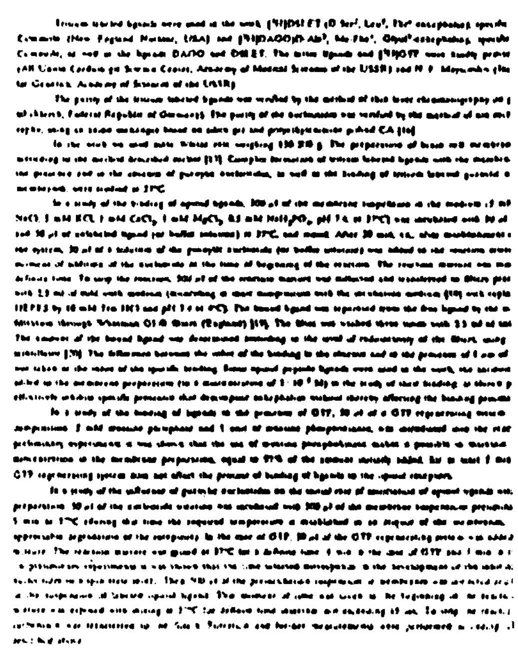
A1 - Handwritten Text



A2 - Circuit Diagram

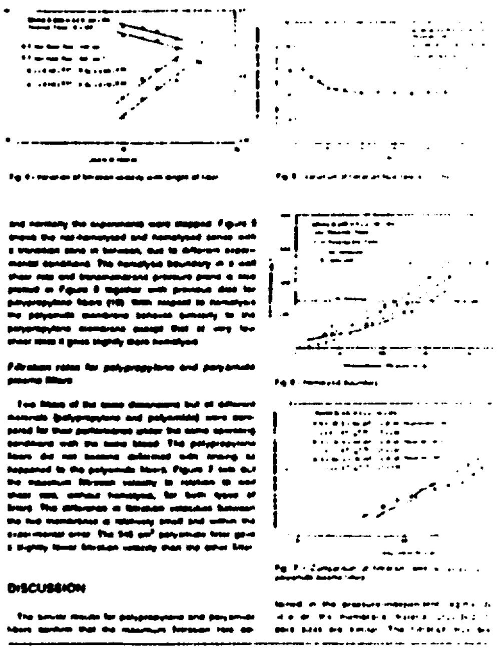


A3 - Financial Statement

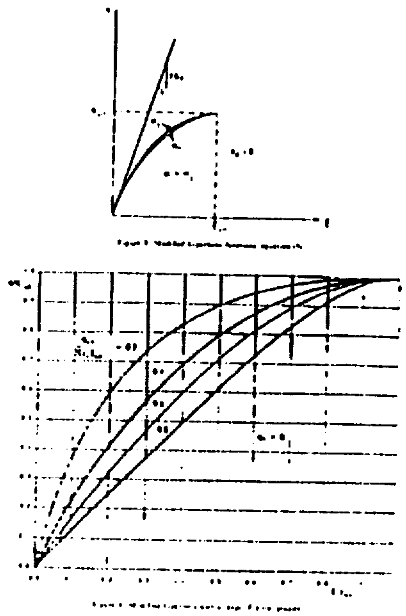


A4 - Typewritten Text

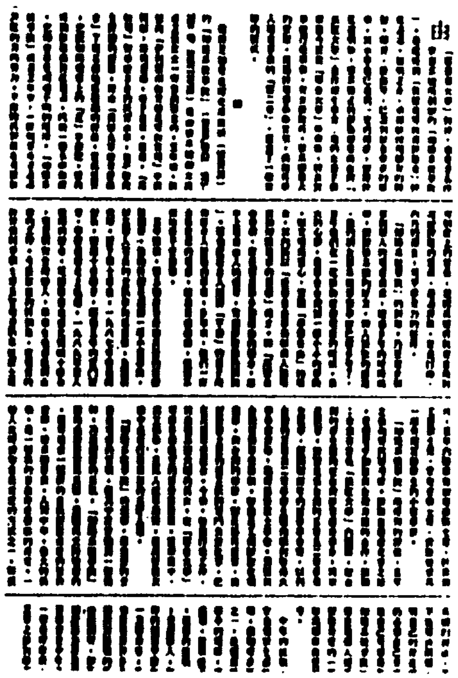
Figure 5. Original Test Images Used for IBC (A1 - A4)



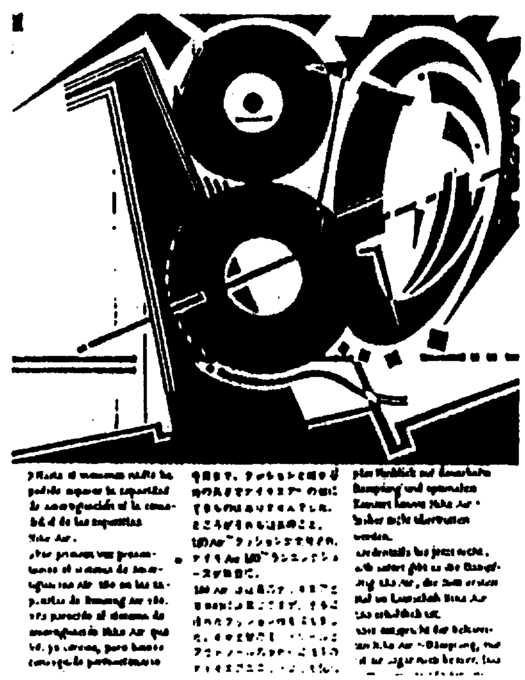
A5 - Sample Page



A6 - Plotting Figure

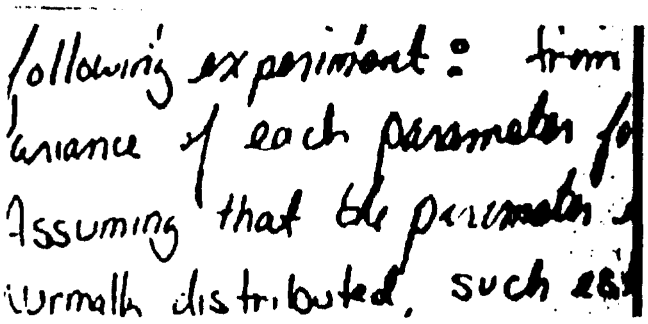


A7 - Chinese Text

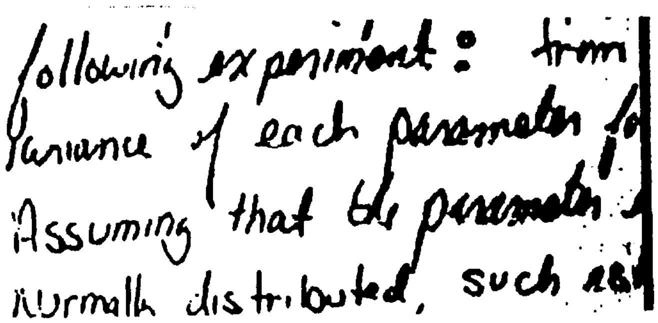


A8 - Trademark Design

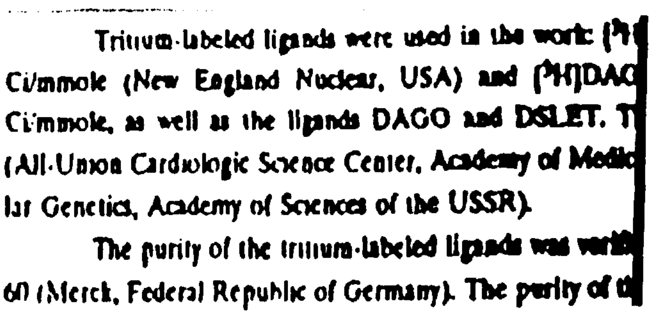
Figure 6. Original Test Images Used for IBC (A5 - A8)



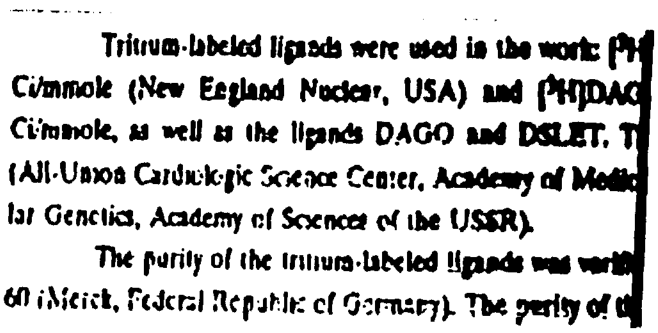
(a) A1 Section, Original



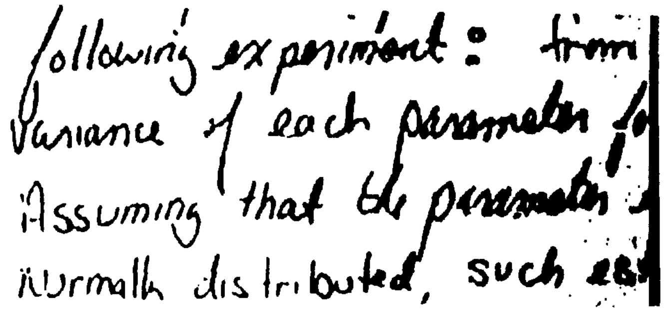
(b) A1 Section, Reconstructed



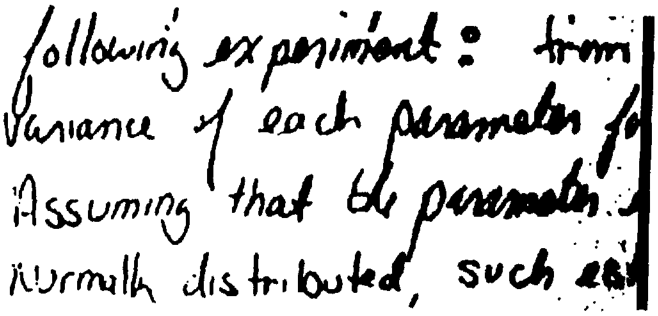
(c) A4 Section, Original



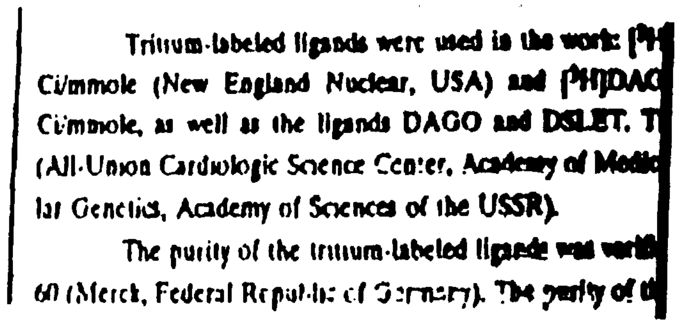
(d) A4 Section, Reconstructed
Figure 7. IBC Simulation Results, F = 160



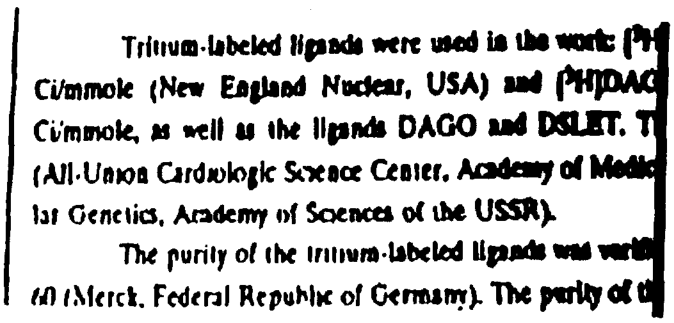
(a) IBC Method, A1 Section



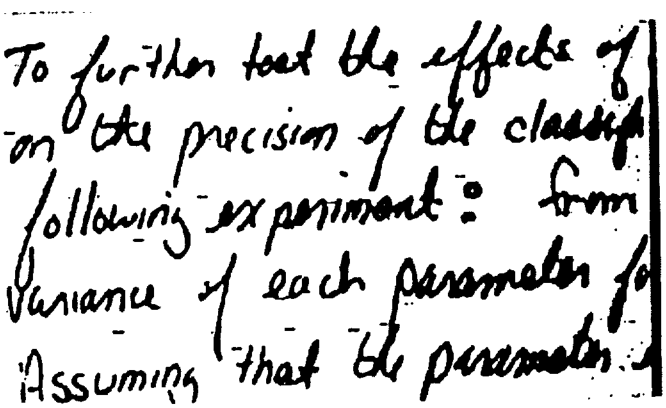
(b) Modified IBC Method, A1 Section,



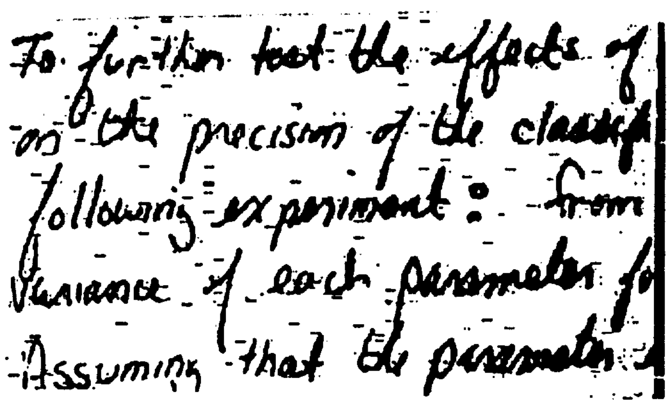
(c) IBC Method, A4 Section



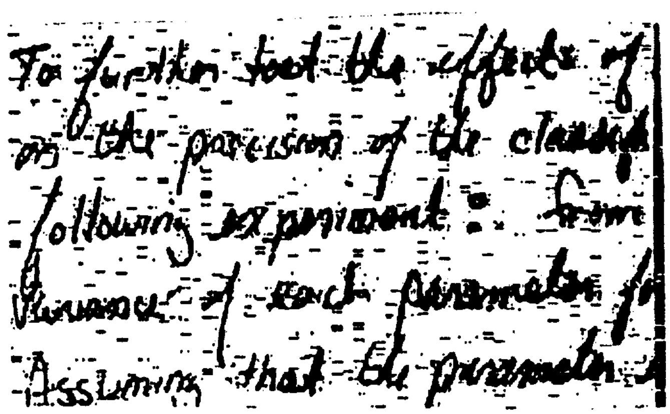
(d) Modified IBC, A4 Section
Figure 9. IBC and Modified IBC Simulation Results F = 64



(a) Error Rate = 1/1000

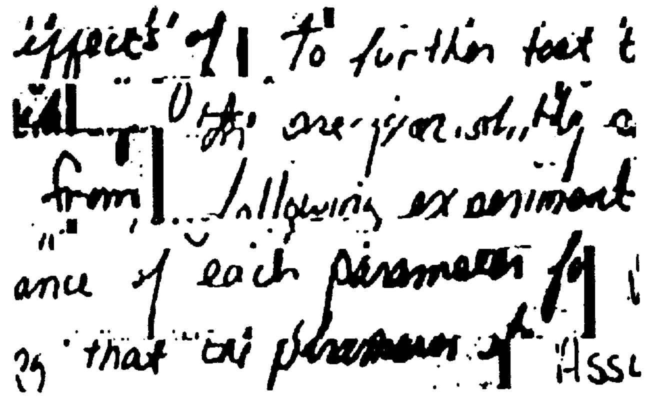


(b) Error Rate = 1/100

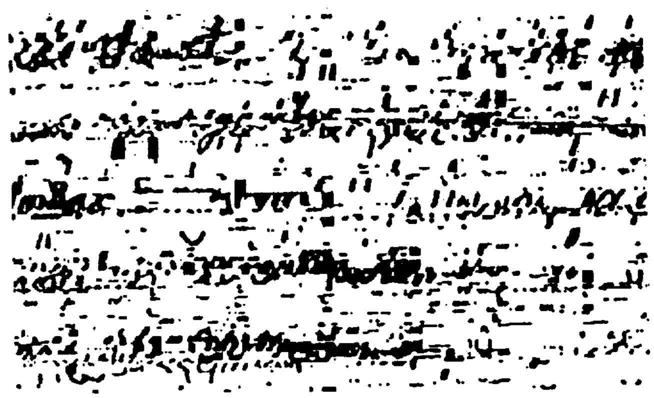


(c) Error Rate = 1/32

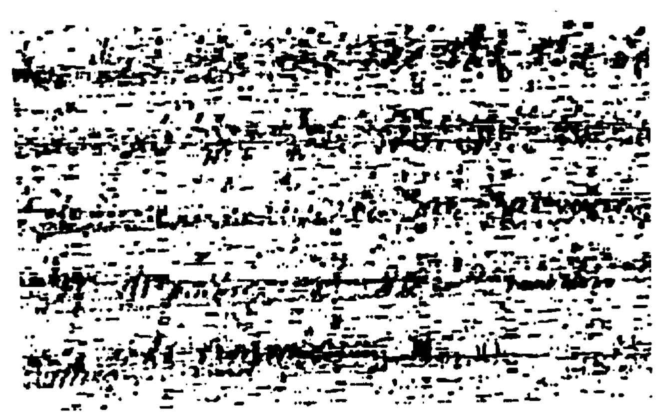
Figure 10. Reconstructed Image in Presence of Random Transmission Errors for Modified IBC Techniques, F=64



(a) Error Rate = 1/1000



(b) Error Rate = 1/100



(c) Error Rate = 1/32

Figure 11. Reconstructed Image in Presence of Random transmission Errors for WBS Techniques