REDUNDANT AREA CODING SYSTEM (REARCS)

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Summary Redundant area coding was proposed in an Air Force patent, James Maier inventor, to relieve the long integration time required to transmit a reconnaissance photograph through narrow-band communication circuits where upper limits of 4800 to 9600 bits/second prevail. Further development by Radiation Systems Division was funded by Rome Air Development Center's Reconnaissance and Intelligence Division. Mr. Lawrence Gardenhire developed the analysis curves used. As redundant area coding was conceived, unimportant areas were reduced by applying different orders of resolution throughout one frame of imagery, by blanking redundant areas, or by applying encoding so one frame could consist of areas basically unchanged and areas coded to represent special land such as Forest or desert. What evolved were techniques of applying redundant reduction algorithms in both areas, producing a low/ high resolution picture. Where 3 to 1 reduction ratios were optimum for an average "busy" picture, reduction ratios exceeding 10 to I have been realized. A 9 x 9 inch, 2000 x 2000, 6-bit grey level picture that required 42 minutes to send at a 9600-bit/ second rate, or about 14 minutes for a 3 to 1 reduction, can now be sent in 5 to 6 minutes. A 10 to 1 reduction ratio makes transmitting imagery through existing ground circuits more of a reality and fulfills user requirements.

Introduction One of the most perplexing problems yet unsolved is how to transmit updated imagery to commanders of tactical forces efficiently and in near-real-time so the almost indispensable imagery can be scrutinized by decisionmakers and timely decisions made. In combat theaters the Air Force has had to disseminate imagery by courier aircraft and other courier services. To add to the problem, existing Air Force ground communication channels are narrow-band, voice-grade quality. Thus, if one recently proposed solution - that of using an imagery transmission system over ground communications for fast, reliable, up-to-date service - was to be implemented, some means had to be found of sending reconnaissance imagery high enough in quality yet low enough in data to realize a near-real-time transmission through existing voicegrade circuits in a manner that al I owed encryption of the data.

Techniques for reducing data evolved as a result of space exploration and its needs; its application to imagery is not new. It is the combined use of several of these reduction techniques with varying tolerance levels that is novel, and the acceptance of such a technique must come from the users. The most attractive combination of techniques is to use a statistical code within the target (nonredundcnt) areas and apply a zero order step reduction algorithm with a line-dropping and line-repeating capability within the non-target (redundant) areas. This combination provides good resolution with no information loss within the prime target areas, and low resolution in the redundant portions.

The application of a low-resolution, high-tolerance level picture has been reported recently by C. M. Knight, J. E. Hartman, and N. F. Shien in a Mitre Technical Report entitled "Evaluation of Data Compression Methods for Image Transmission." It is felt that this quality of picture is adequate for the redundant area of the reconnaissance imagery, and that enough data is presented to provide a good visual interpretation of landmarks for navigation purposes. Furthermore, a computer software effort that simulates the system design has been completed; results are presented in this paper.

Objective Requirements exist which call for the transmission of imagery at upwards of ten line pairs/mm and for a format size of 9 x 9 inches. The typical "busy" photograph can provide reduction ratios of only about 3 to I through the use of the fan or step reduction algorithm. With these facts in mind, the first objective of the Redundant Area Coding Study was to analyze all of the different techniques and determine parameters that could be utilized to predict theoretically the reductions that could be expected through narrow-band voice channels.

Another objective was to evaluate all of the known techniques of coding redundant and nonredundant areas. Generally, these techniques were divided into two classes. One class involved a "blanking" concept, through the use of stylized/symbolic background within the redundant area, or through a completely blanked redundant area, or through the use of a pattern to be filled in at the receiver. The second class incorporated algorithms within both the redundant and the nonredundant areas. In this class several algorithms were tried. They were subjected to an analysis, so curves could be supplied for estimating the approximate reduction ratio expected from selected combinations of algorithms.

Display and Designation of Redundant Areas Fundamental to any reduction of redundant areas in a photograph is the determination of exactly which areas are redundant. Since to different users, different areas would be classed as redundant, no one area can be arbitrarily classified as always being a redundant area. Consequently, only trained personnel accustomed to evaluating photographs are capable of designating the redundant areas. At the present time, the photo interpreter is the only person qualified to perform this task. The techniques discussed in this section will serve as additional tools that can be used to transfer the specific information needed by the user. Figure 1 shows a typical photo with nonredundant areas outlined.

Two different approaches are applicable to the designation of re un ant areas. One is to designate the areas of little value to the user and assume that the other portions are prime areas. The alternate approach is to designate the areas of prime importance and assume that all the other areas are of little value to the user. Techniques using both of these approaches are discussed in this section; several of them could be used in either way. Although the first approach appears to be the more straightforward, the second approach is so similar to current practice that it would probably require little change in procedures. In selecting any designation technique, a major constraint is the fact that the technique used must be machine detectable so the photographic data can be separated into redundant and nonredundant data. This machine detection allows the different areas to be processed independently; it also permits application of the optimum reduction algorithm for each type of data.

Redundant Area Display Techniques After redundant areas are designated and transmitted, some means of displaying them on the receiver end of the transmission link must be used. To determine the best means two basic tasks must be accomplished. First, the exact location of the redundant area must be defined in relation to the remainder of the photo and second, the nature of the redundant area must be specified. Both of these parameters are of prime importance to the user of the photo copy.

Although many different display techniques can be designed, the display technique chosen is somewhat dependent on the way redundant areas are designated on the transmitter end. The display of the redundant area is the end product of the process started at the transmitter end and, therefore, is considered a part of the process and not a process within itself. Each of the three types of techniques (data reduction, pictorial simulation, and symbols) discussed in this section describes not only a display technique, but also a technique to be used on the transmitter end to designate a redundant area. This section also gives the advantages and disadvantages of each technique from a display point of view.

The techniques summarized in subsequent paragraphs are grouped under data reduction, pictorial simulation, or symbols. Each of the variants developed within the basic grouping is included in the summary.

The data reduction grouping is divided into Low Resolution, Line Mapping, and General Data Reduction Techniques. The Low Resolution Technique involves displaying the prime areas at high resolution and the remainder of the photo at a lower resolution. The resolutions selected by the photo interpreter before the photo is transmitted would be based on the degree of detail needed by the user. When this technique is used, only the dominant Features of the photo appear on the photo copy. The photo copy resembles a hand-drawn sketch of the area and contains all the basic information of the original. The output copy of the General Data Reduction Techniques looks approximately the some as the output copy of the Low Resolution Techniques.

The one major advantage of the General Data Reduction Techniques is that the output copy is of better quality than that gained by using the Low Resolution Technique even when less data is transmitted. The General Data Reduction Techniques include the step, extended step, statistical encoding, and others. These techniques can be applied to the entire photo with significant data reduction and very little degradation of the output copy. Most of these techniques compare sampled data with some predetermined bound and transmit the sample only if it falls outside a set tolerance. The tolerances are automatically adjusted to reflect whether the area being sampled is inside or outside a redundant area.

The pictorial simulation techniques replace the designated redundant areas with simulated photo data that is an approximation of the original areas. The first pictorial simulation technique discussed is Feature Mimicking. In this method no photo data is transmitted when inside the designated redundant area. Instead, a code corresponding to the redundant areas is transmitted. On the receiver end, the code is decoded and a generator is started to simulate the proper photo data in the redundant areas of the copy. In the second technique, called Reproduction of a Sample, only a PI-selected sample of the redundant area is transmitted.

The last type of display discussed uses symbols. They are divided into two techniques: Stylized Symbols and Map Symbols. When these techniques are used, the transmitter operator covers all of the redundant areas of the photo with either paint or pressure-sensitive symbols. The nature of the redundant area is specified by placing, on the covered area a map symbol or a paste-on symbol, or by simply writing the name of the area on the covering.

Comparison of Techniques The General Data Reduction Technique offers the most information to the user from the least amount of transmitted data. Furthermore, this technique can easily be adopted to all types of redundant areas by regulating the resolution and tolerances of the reduction algorithms. In addition, the electronics used to implement these algorithms are relatively simple and straightforward. The Line Mapping Technique also has definite advantages for the user in that it gives him the important lines of redundant areas in sharp contrast. In some cases, however, it may be difficult for the user to determine what the lines on the copy represent. The Feature Mimicking Technique is not only difficult and expensive to implement, but the output copy could be very misleading. The Reproduction of a Sample Technique gives more information and provides greater flexibility than Feature Mimicking, but neither technique shows the characteristic lines of the redundant areas. Furthermore, they offer almost no information to the user. The techniques using symbols provide a minimum of information to the user. They also require considerable time to prepare the photo for transmission. Detailed explanations and discussions of each of the techniques presented briefly here are given in the following paragraphs.

Data Reduction Low Resolution, Line Mapping, and General Data Reduction Techniques can be applied to the entire photo; however, in this paragraph they will be discussed only as to their effect on the display of the redundant areas. When any of these techniques are used, the amount of data transmitted in the redundant areas is greatly reduced. As a result the redundant areas are displayed in much poorer quality than the other parts of the photo.

The Low Resolution Technique is one of the simplest forms of data reduction. When the scanner posses into the redundant areas (previously designated by the transmitter ,operator), the sample rate is greatly decreased. On the receiver end the redundant areas appear in much lower resolution than the other parts of the photo copy. Refer again to Figure 1, which illustrates one method of designating nonredundant areas, and to Figure 2, which shows the copy the user receives.

The redundant areas of the photo copy look somewhat similar to the actual area on the original, permitting the receiver operator to get a rough idea of what the area actually looks like. This rough look gives a definite advantage over simulated data where there are no subdivision groups. Another advantage of this technique is that no additional work is required of the operators thus reducing the possibility of human errors. Although the Low Resolution Technique is a simple form of data reduction, Ns does not mean that it is more economical . It requires the design of control circuitry to regulate the sample rate on the transmitter end. The low resolution technique also requires the transmission of a considerable amount of data even for the redundant areas. Another drawback is that of determining the proper resolution for different types of redundant areas, so each can be recognized on the receiver end.

Line mapping is a form of image enhancement in which only the predominant lines of a picture are reproduced. When the scanner is inside the designated redundant areas, only one of two gray levels are transmitted: either black or white. The data obtained from the redundant areas is sent through a circuit that recognizes only very abrupt changes. These abrupt changes comprise the transmission. On the photo copy the redundant areas are displayed as profiles of the area. A si mu lated photo copy of the original photo is depicted in Figure 3.

The major advantage of the Line Mapping Technique is that the data transmitted for the redundant areas is greatly reduced. In addition, the highlights of the redundant areas appear on the photo copy and would be easily noticed if the actual area were quickly scanned. Furthermore, additional operator time is not required. On the other hand, additional hardware is needed. This equipment consists of a differential circuit to distinguish the profiles of the redundant area, and control logic. A second disadvantage is the potential difficulty of distinguishing the nature of the redundant area from its profile. For example, a wall may appear the same as a building if only the profiles of each are copied.

General Data Reduction Techniques are those used to minimize data transmission over the entire photo. In general, they compare a sample with a predicted sample or projected bounds to determine if it is within a preset tolerance. If it is within this tolerance, the sample is disregarded; if it is not, the sample is transmitted. Among the many existing methods are step, fan, and delta processes; all produce similar results on the photo copy. The tolerances for the data reduction are greatly increased when the scanner enters the designated redundant areas to produce a resolution For the redundant areas that is much lower than the other parts of the picture.

The major advantage in using these general data reduction techniques is the minimum increase in hardware. In addition, these techniques eliminate the need for a change in data format between redundant and nonredundant areas. On the receiver end, no additional work is required of the operator and the copy photo will contain practically all the information available on the original. Few of the disadvantages of other techniques apply to General Data Reduction Techniques. The main factor concerns whether or not the technique is used for the entire photo. If it is not, then to use it in the redundant areas only would require the addition of hardware and control logic. On the other hand, if the technique is used for the entire photo, then only the control logic for the tolerance limits would need to be designed.

Pictorial Simulation Any pictorial simulation method involves the replacing of redundant areas at the receiver end by some kind of picture that resembles the actual photo. Feature Mimicking and Reproduction of a Sample Techniques are two methods of pictorial simulation.

In the Feature Mimicking Technique no picture data is transmitted when the scanner is inside the areas designated by the transmitter operator as redundant. Instead, a code is transmitted to the receiver where it is decoded and a signal generator is started to generate data to simulate the redundant areas. This data is then transferred to the redundant areas in the photo copy. In Figure 4 the redundant areas are outlined; Figure 5 illustrates the photo received when this technique is used.

The Feature Mimicking Technique requires very littl e operator work on either end of the transmission link, thus minimizing the chance of human error. The major disadvantage is the additional hardware required for this method. Feature mimicking would require an encoder and decoder to accommodate all the different types of redundant areas. It would also require a very complex signal generator. This hardware would add considerable cost to both transmitter and receiver. Another disadvantage is the fact that the photo copy may be quite misleading as the redundant areas may be difficult to distinguish. And, unless the signal generator is capable of generating an infinite number of patterns, the redundant areas of the copy may vary greatly from those of the original.

When the Reproduction of a Sample Technique is used, only a small sample of the redundant area data is transmitted. The transmitter operator designates the redundant areas and the size of the sample to be transmitted for each such area. When the scanner is inside the redundant areas, only the designated sample is transmitted; the remaining redundant data is discarded. On the photo copy the redundant areas are blank except for the small sample. Figure 6 is the original photo for which the operator has designated redundant areas as well as the size of the sample to be transmitted. (This method is one of a number of ways to produce the some results on the receiver end.)

The major advantage of this technique is that the sample of the redundant area on the copy looks the some as the sample designated by the transmitter operator. In addition, the redundant areas are easily recognized and the receiver operator is not required to do any additional work. The fact that the transmitter operator must determine how much of a sample of the redundant area to transmit is a disadvantage because the transmitter operator must decide how much data is required for the receiver operator to recognize the nature of the redundant area. Figure 8 illustrates a received copy with the samples filled in.

Standard Picture In order to make comparisons of different encoding schemes that would reduce the transmission bandwidth of scanned reconnaissance photos, a standard format for the digital picture was developed for the study. All photos, regardless of size, contained the some number of lines and the some number of bits. If a higher resolution was desired, a portion of a picture was enlarged either optically or photographically. Considering a 9 x 9 inch photo to be the largest and requiring the least resolution, 222 lines to the inch (a total of 2000 lines) was chosen as a base. If 2000 lines are used on a 5 x 5 photo, there will be 400 lines/inch. If higher resolution is desired, a smaller portion of the picture can be enlarged to produce the desired resolution.

Once the number of lines was chosen, the samples/line were selected so vertical and horizontal resolution are the some. Assuming the Kell factor has been maintained at the proper value, in a square picture there will be the some number of elements in a line as there are lines. Based on this assumption, the standard picture of two thousand lines has

4×10^6 six-bit elements, or 24×10^6 bits. For the purpose of this study, line and frame synchronization were not considered, since any picture transmitted would require the same amount of synchronization and would not, therefore, affect the results of this study. The following figures show the time required to transmit the standard picture over some of the existing modems.

TRANSMISSION TIME OF STANDARD PICTURES

Modems (kilobits)	2.4	4.8	9.6	24.0	48.0	240.0
Transmission time (minutes)	166.67	83.33	41.67	16.67	8.33	1.67

From the many pictures scanned and reduced by various encoding schemes, the two having the most (Figure 9) and the least amount of information (activity) (Figure 10) have been determined. Since these illustrations are not typical reconnaissance photos, they have been used only to establish the limits for this study. When these two pictures are used with statistical coding in the target area and adaptive step with every fifth line transmitted in the redundant area, Figure 11, which is a summary of coding schemes versus the transmission time for a standard 2000 x 2000 picture, results. The percentage of target area is shown on the vertical scale and time is on the horizontal scale, with zero percentage representing all redundant areas. The minimum and maximum pictures start at 1.5 and 2.3 minutes, respectively. As the amount of target area increases, the transmission time also increases; therefore, with a 12 to 13 percent target area, the goal of 10 to 1 reduction can be obtained. The dotted lines show six-bit PCM in the target area. The difference between the dotted line and the related solid line is the improvement the statistical code provides without degrading the target areas.

Summary of Techniques After all the techniques were scrutinized together with the reductions expected from each, it was determined that the Low Resolution Technique provided more of a “real” picture than the other, and that the low-resolution areas yielded enough information to give a decisionmaker - such as a commander or tactical pilot - a summary of all the outlined areas. The low/high resolution method was further investigated in order to include various algorithms within both redundant and nonredundant areas. These variations are also shown in Figure 11 .

From all of these combinations, the statistical code within the nonredundant areas combined with the extended step redundancy reduction algorithm within the redundant areas was considered to afford the best reduction ratio with the least amount of data loss. The statistical code produces no information loss within the confines of the nonredundant areas and the step algorithm, with every fifth line dropped, furnishes adequate representation of the redundant information. If the nonredundant data is 30 percent of a picture, it could be transmitted in 8.4 minutes; if the nonredundant information forms

20 percent, transmission time would be 6.3 minutes. With the advent of Redundant Area Coding, transmitting moderate-resolution imagery in important areas in near-real-time has become more of a reality.

Implementation of REARCS In order to demonstrate the operation of the Redundant Area Coding System (REARCS), a program was established that combined hardware and software in the implementation. The hardware is an image terminal and a digital tape recorder. All reduction algorithms are implemented in machine language software in such a way that they can be processed on a small computer with limited memory. The image terminal is a drum-type loser scanner, which can also be used as a reproducer. It is capable of scanning or reproducing an 8 x 10 inch maximum picture and a 1 x 1 inch minimum picture. Any combinations of 1 x 1 grids may be scanned or reproduced. The image terminal has a resolution of 64 to 1024 lines/Inch in binary steps. The optics and sampling ore always arranged for a 0.7 Kell Factor in both directions.

During implementation the standard picture was changed from a 9 x 9 at 200 lines/ inch to an 8 x 8 at 256 lines/inch in order to facilitate the reproduction of pictures in reports without reducing them. This change makes the standard picture 2048 samples by 2048 lines. As before, this value holds for all resolutions above 256 lines/inch; that is, all pictures have the some number of samples, with the higher resolution ones being smaller: 4 x 4 for 512 lines/inch and 2 x 2 for 1024 lines/inch.

One or more of the 1 x 1 grids can be designated by an operator as the nonredundant area. Al I I Ines inside this area will be statistical ly encoded while the area outside the nonredundant area may have up to 8 lines and samples dropped. At the reproducer, the lost transmitted line is reproduced the number of times the operator had called for. In addition, the data may be source encoded, using the extended step algorithm with selectable tolerance of 1 to 6 levels in 64. The nonredundant area thus will always be statistically encoded, and will produce a reduction from 6 bits/element to about 2.75 bits/element in that area. If the area is 1 x 1, inch with a resolution of 256 lines/inch, the 393,216 bits will be reduced to about 175,000 bits.

If the entire picture is encoded, the 25,165,824 bits can be transmitted over a 9.6-kilobit/ second line in 19.91 minutes. Figure 12 is the resulting picture. This picture has been scanned at 256 lines/inch, sampled to 2048 samples/line, digitized to 6 bits, source encoded, transmitted over a 9.6-kB line, decoded, and reproduced. In Figure 13 there are six 1 x 1 inch grids considered to be nonredundant (9.4 percent of the total picture) in two separate areas: a 2 x 2 inch square in the area of the ships on the lower side of the harbor, and a 1 x 2 inch strip of the wharfs across the top of the picture. These areas are processed the same as in the previous figure (reduced to about 2.75 bits/elements by statistical encoding), while in the remainder of the picture, every fourth sample and line is repeated three times. In addition, the remaining samples are source encoded using the extended step algorithm with a tolerance of 2 levels in 64. This reduces the original 25 million bits to about 2.8 million bits, which can be transmitted over 9.6-kB line in 4.8 minutes, for an overall reduction of 9.1 to 1 .

Had adaptive tolerance been used, the streaking in the nonchanging areas (water) would have been improved by dropping the tolerance to a 1 level in these areas and increasing the tolerance to 3 or 4 in the active areas.

Conclusions The last two pictures (Figures 12 and 13) show that it is possible to reduce the time needed to transmit a standard picture from about 43 minutes to 5 minutes over a 9.6-kB link, while maintaining the original resolution in the target area and supplying the pilot the needed orientation information in the redundant area. The equipment required to perform this function is relatively simple and inexpensive. The Redundant Area Coding System reduces the turn-around time for getting annotated photos to the strike forces by many magnitudes.

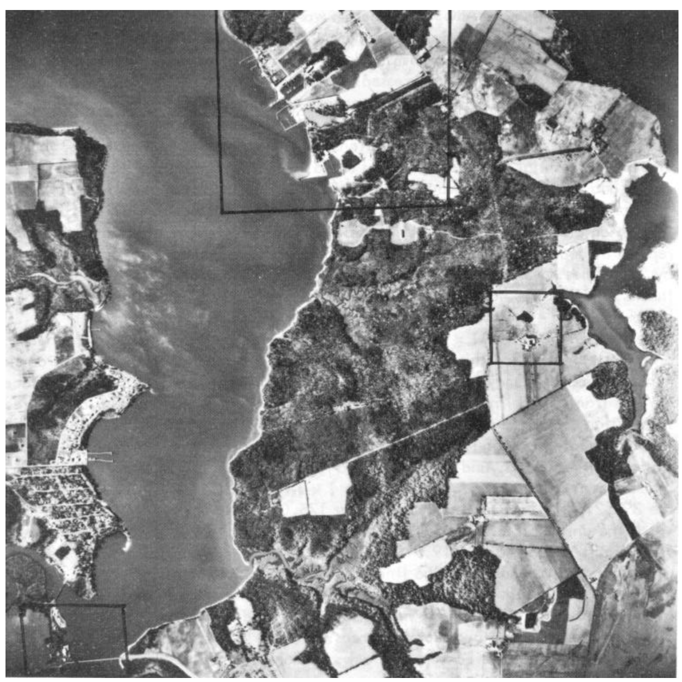

Fig. 1 - Typical Photo with Nonredundant Areas Outlined

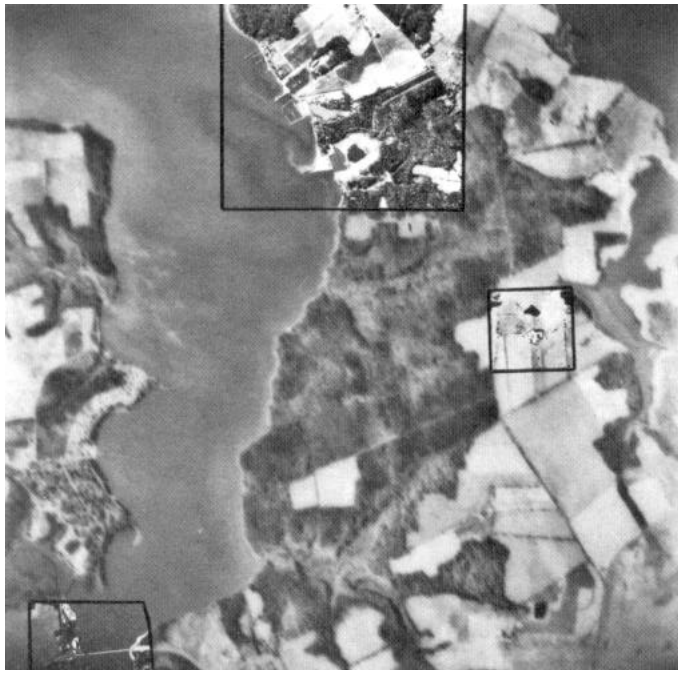

Fig. 2 - Received Copy, Low Resolution Technique

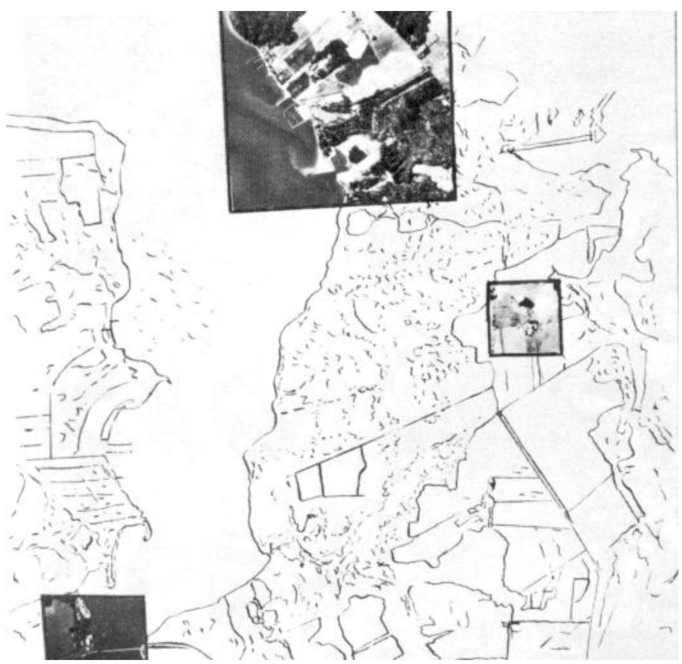

Fig. 3 - Received Copy, Line Mapping Technique

Fig. 4 - Typical Photo with Redundant Areas Outlined

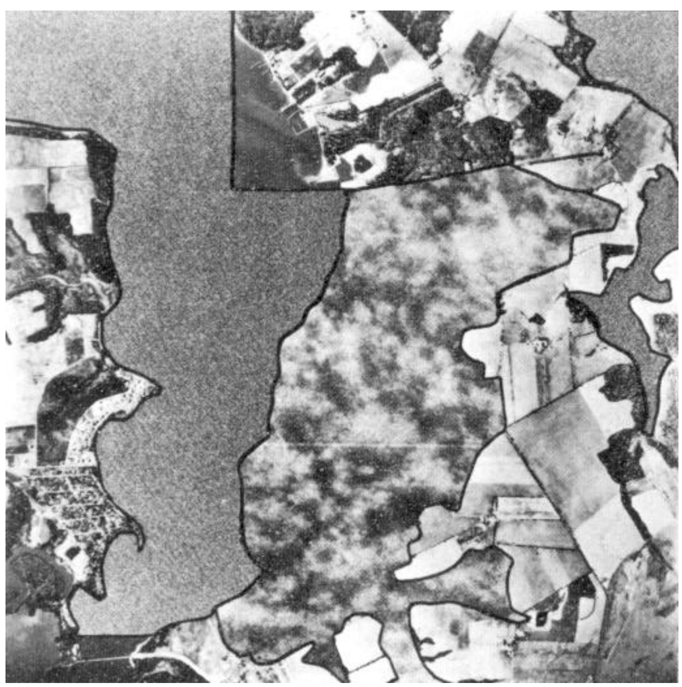

Fig. 5 - Received Photo, Feature Mimicking Technique

Fig. 6 - Typical Photo with Samples Designated

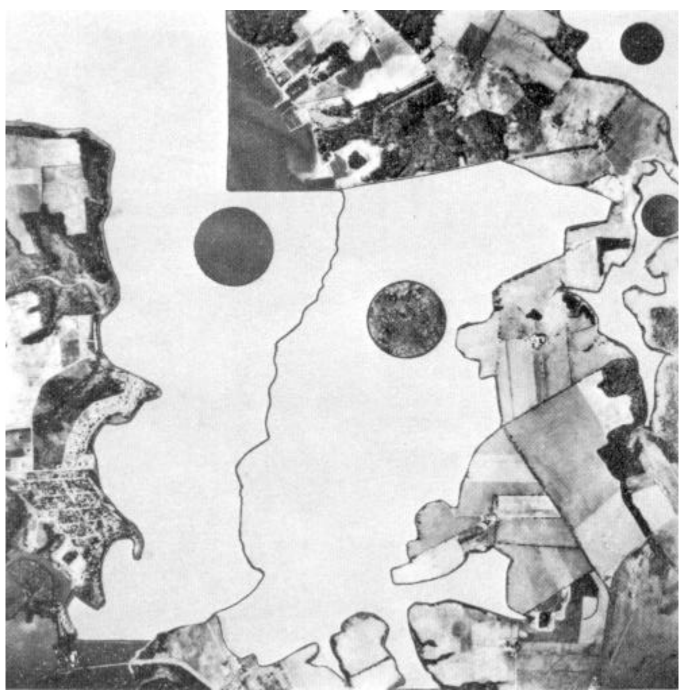

Fig. 7 - Transmitted Information in Reproduction of a Sample Technique

Fig. 8 - Received Copy with Samples Filled In

Typical Maximum Picture
Original Picture 9" x 9" 200 Lines/
Inch 15,000 Bits/Line 1800 Lines
4.5 x 10^6 Six-Bit Picture Elements
27 x 10^6 Bits in Picture

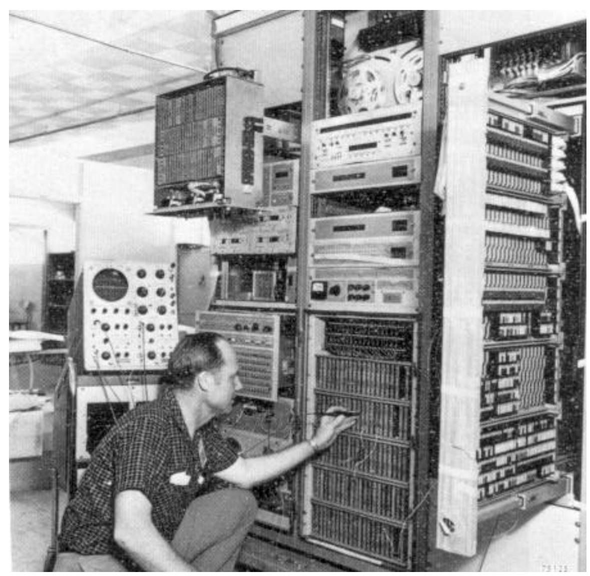

Fig. 9 - Maximum Activity Picture

Typical Minimum Picture Original
Picture 9" x 9" 500 Lines/Inch
39,000 Bits/-Line 4500 Lines
29.25 x 10^6 Six-Bit Picture
Elements 175.5 x 10^6 Bits
In Picture

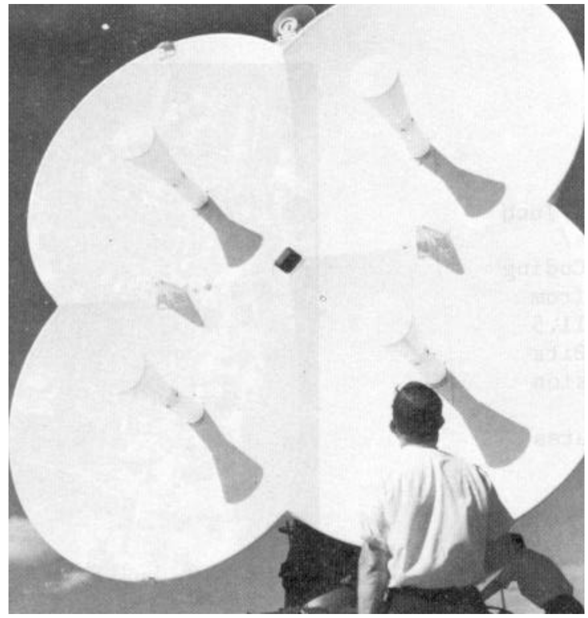

Fig. 10 - Minimum Activity Picture

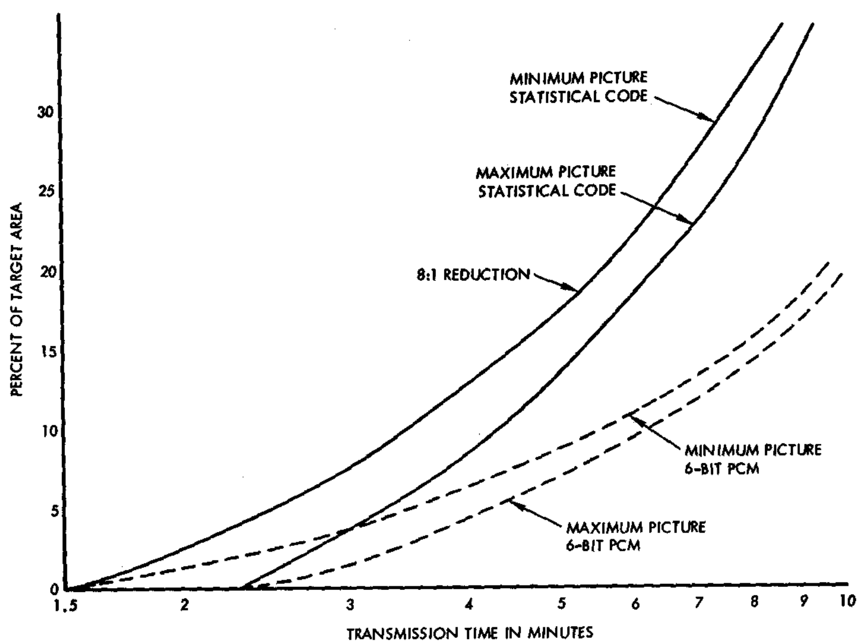

Fig. 11 - Summary of Coding Schemes Versus Transmission Time

256 Lines/Inch 2.75 Bits/Element
Coding Reduced from 25.6 to
11.5 Million Bits Transmission time
19.9 Minutes

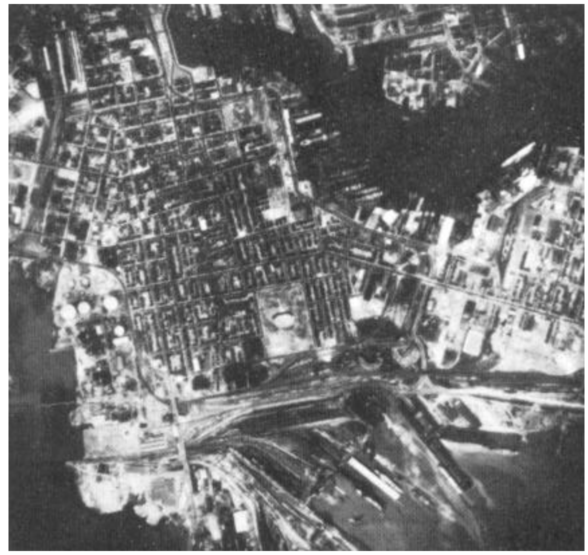

Fig. 12 - Statistically Encoded Picture

Statistical Encoding in Nonredundant
Areas Extended Step Encoding
in Redundant Areas with Tolerance
of 2, with every Fourth Sample and
Line Repeated 3 Times reduced from
25.6 to 2.8 Million Bits Transmission
Time - 4.8 Minutes

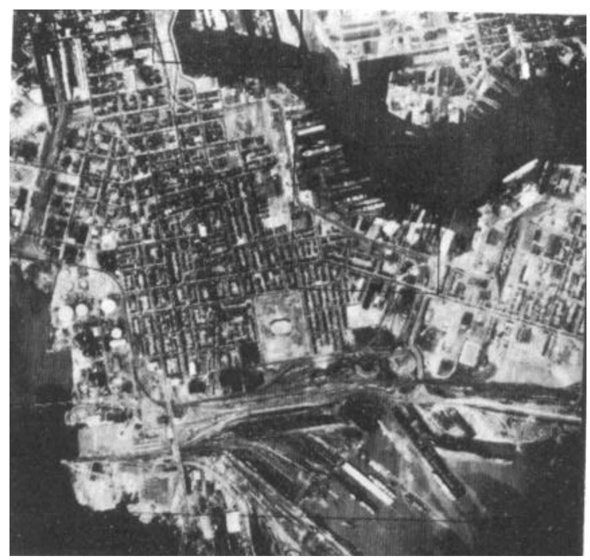

Fig. 13 - REARCS Picture with Two Nonredundant Areas