Scan Methods and Their Application in Image Compression

Tarek Ouni and Mohamed Abid
CESLAB, National Engineering School of Sfax,
University of Sfax, 3038, Tunisia

Tarek.ouni@gmail.com, mohamed.abid@enis.rnu.tn

Abstract

The exploitation of SFCs in image compression could constitute an attractive alternative for efficient image coder design. Different ways of SFC exploitation have been explored in the literature. In this paper, we present a comparative study of different SFC based compression methods. This study includes the specification of new scan or SFC evaluation metrics, the presentation of different methods basics, the evaluation, classification, modeling of existing method and the analysis of their potential usage in image compression.

Keywords: *SFC, adaptive scan, image, Compression*

1. Introduction

Exploring the content of an image depends, among other things, on the way in which it is scanned. For example, information obtained by scanning the image horizontally differs from those obtained by scanning it vertically. Since there are several ways to scan the image, there are also several possible interpretations of its content. Thus finding the scan that provides more useful and relevant information of the image can be useful for image processing. In the compression context, efficient scanning must be able to explore most redundancy in the image. However, among existing encoders, the most used scan is the scan line (row by row or column by column). The GIF [23] encoder for example, scans the image line by line while projecting the pixel values in a vector, then it applies dictionary coding (LZW) to remove statistic redundancies. Therefore, horizontal patterns (redundant sequences) are effectively compressed but vertical patterns are not [1-4]. It is evident that the performance of such coding depends partly on the way in which the image was scanned. Thus, searching a way to find the most suitable scan may be useful for image compression compression. The question then arises. Given a sequence of random variables such as pixels intensity in image, what is the best scan order for the encoding?

As a response to this question, several static and adaptive scan methods, called space filling curves (SFC), have been proposed in the literature as alternative of conventional linear scans [4-17]. The goal of such approaches is to explore correlations in the image to turn them into a strong correlation in the resulting linear pixels sequence which is easily exploitable for purposes of compression. Such approaches offer the ability to design, at low cost, new coding schemes.

In this paper, we present a synthesis of different works on the SFCs exploitation in image compression. The originality of this study could be resumed in three points. First, we propose a model based classification of existing methods which is able to ensure an easy comprehension of their strategy of works and their potential. Second, we introduce some new metrics for scan methods evaluation which facilitate their performances comparison. Third, we separate between the scan method efficiency and the compression model in which each considered method it was introduced. This point is mandatory as it allows detecting the main contribution of the scan in image compression.

In Section 2, we firstly present static SFCs and its application in image compression. Then, we introduce adaptive scan methods as a natural extension of static ones. In Section 3, we present a consistent study of these methods. This study includes the specification of new scan evaluation metrics, different methods study, evaluation, classification and modeling. Then we discuss their potential usage in image compression. We finally conclude with a short summery.

2. Scan and Compression

The scanning process transforms the 2-dimensional image into 1-dimensional representation. Various image scanning algorithms focus on the nearby pixel similarity in the image. They are designed to exploit this characteristic to improve the autocorrelation in the resulting 1-dimensional image representation. Image scanning using SFCs is a typical example of such algorithms.

2.1. Generic SFCs

An SFC defines a continuous scan that traverses through image pixels exactly once. The resulting sequence of pixels is then processed as required by the corresponding application.

To obtain the image after processing, the (possibly modified) pixel-sequence is placed back in a frame along the same SFC. In compression, it is important that the intra-pixels correlation in the image is translated to an appropriate autocorrelation within the pixel-sequence [22].

It is worth mention that SFCs are explored in order replace the conventional line-scan by other forms of more appropriate scans. The majority of researches converge to fractal curves.

Additionally, the scan-line is a standard scanning method, which traverses a frame line by line. It is well known, however, that SFC's, which are defined recursively, end up with more favorable properties than the scan-line. Intuitively, the recursive nature of the SFC requires it to traverse neighboring pixels before moving to more distant ones, resulting in better exploitation of the two-dimensional locality. These SFCs tend to minimize the differences between the Intra pixel distances in the image (distances in 2D image space) and ones in the generated pixel sequence (1D representation). The most popular recursive SFC is the Peano-Hilbert curve, which has been considered for numerous applications [4, 6, 7, 8]. The Peano-Hilbert curve is particularly used as it has an inherently strong locality property: it never leaves its current quadrant, at any level of refinement, before traversing all the pixels of the quadrant (see figure 1). This property, as well as pseudo-random changes of directions, implies that Hilbert and Peano scans work well, from the statistical point of view, for a large family of images [11].

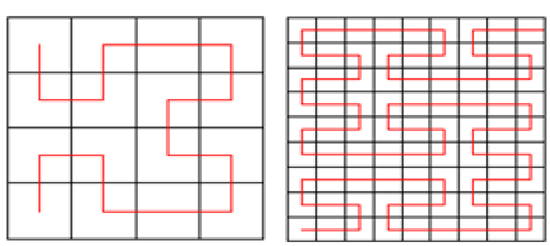

Figure 1. Hilbert (left) Péano (right) Curves of Order 2

Lempel and Ziv showed [18] that the entropy of the pixel-sequence obtained by using the Peano-Hilbert scan converges asymptotically to the entropy of the two-dimensional image. Thus, the compression using the Lempel-Ziv encoder [19] in a system of image compression is optimal in the sense of information theory.

Matias and Shamir considered [20] the relationship between the two-dimensional autocorrelation of an image and the one-dimensional autocorrelation of the pixel-sequence. They showed that, for first-order Markov isotropic images, the autocorrelation of the pixel-sequence is a function of the fractal-dimension n of the SFC. Hence, the Peano-Hilbert curve for which v = 2 (highest possible), gives the best autocorrelation, compared with a random SFC (as in Figure 1) for which v= 4/3, and with the scan-line, for which v = 1 (lowest possible). These studies support the approach that recursive SFCs, such as the Peano-Hilbert curve, would be a good choice as a universal SFC that would work well (statistically) for large families of images.

However, such scans independent of image content are far from being optimal. To achieve more optimality, each image must have a suitable scan that takes into account its own characteristics. Therefore, the trend turned towards the search for an adapted scan.

2.2. From Generic Scan to Adaptive Scans

The principle of an adapted scan is to assign to each image, or part of the image, a suitable scan that would work well for the particular image while taking into account its own characteristics rather than relying on a universal SFC that works well statistically.

Adaptive scans often go through an image pixels activity analysis stage before specifying the appropriate scan.

Among the studied methods, the setup of the scan path is done along with the image content analysis; the scan can be progressively adapted to the activity of pixels [11, 13]. Other methods include a segmentation based on image content analysis which subdivides the image into homogenous regions. Then regions are scanned by predefined SFCs [12, 14]. In other methods, the scan is set up by combining a number of predefine SFCs. It consists in subdividing the image into blocks and matching each block to a suitable SFC from a set of predefined scans patterns (dictionary) [15, 16, 17, 21]. Thus, we have classified the methods of adaptive scan in three classes; adaptive methods, not adaptive or predefined methods and semi adaptive methods. For each class, we created a model based on the key points that we identified from the scan strategies adopted by the above mentioned methods. In the next, a synthesis of existing methods will be presented.

3. Study of Adaptive Scan Methods

Before studying the different adaptive scan methods, we define some metrics and some terminologies in order to make easy the comprehension and the evaluation of the scan methods.

3.1. Terminologies

Continuous Scan and Discontinuous Scan: a continuous scan is a scan that presents a continuous path. It aims to explore the neighborhood properties of the image. In contrast, a discontinuous scan is performed according to a discontinuous path where it pursues the similarity between pixels regardless of their spatial positions.

Reference Scan: it is a generic scan which we could use as a reference when comparing other uncommon scans. Since the basic objective of adapted scanning methods is to bring more relevance than static scans, we consider as references the line by line scan which is actually the most commonly used scan.

Optimal Scan: We define an optimal scan by the scan able to minimize the entropy of the pixels sequence generated by the scan. An optimal scan as it is presented in figure 2 is able to generate a high correlated pixel sequence at the cost of costly coding additional information.

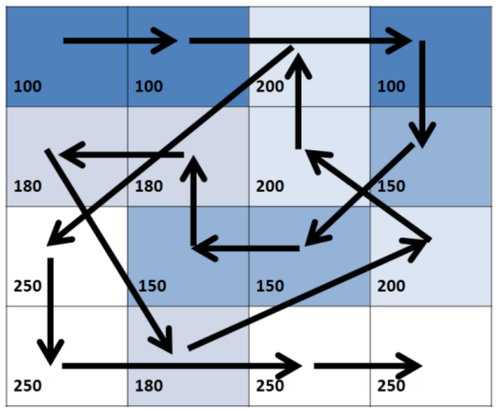

Figure 2. Illustrative Example of an Optimal Scan

Efficiency of a Scan: The usefulness of the scan could come from its ability to decrease the entropy of a signal, to minimize these high frequencies components or to improve its auto-correlation in order to achieve a monotone signal (sequence of pixels) easy to compress. However, this is appreciated when the encoding extra cost due to additional information generated by the scan needed to restore the pixels in their initial order (during the image reconstruction) is less than the coding cost reduction achieved by this scan with respect to a reference scan. Thus, a new metric evaluation, further called efficiency of the scan, seems to be necessary. To get started, some other terminologies are defined:

Encoding Cost: set by the number of bits needed to encode the sequence of pixels generated by a given scan.

Encoding Extra Cost: set by the number of bits needed to encode the path of the scan.

Encoding Total Cost: Set by the sum of the encoding cost and encoding extra cost.

Thus, a given scan method is considered efficient if the encoding total cost is less than the cost of a scan reference encoding.

Subsequently, the efficiency of given scan S is defined as follows:

$$E(S)= \frac{\text{cost of a scan reference encoding} - \text{scan encoding total cost}}{\text{cost of a scan reference encoding}} \times 100$$

Subsequently a scan S is efficient if E(S)> 0.

3.2. Study and Classification of Different Approaches

We present in the following the three elaborated models, while presenting an evaluation of different methods presented as case studies.

3.2.1. Adaptive Model

In this model, the image is scanned according to its content analysis. The model input is the original image. The outputs consist in linear high correlated pixels sequence and the adapted scan code.

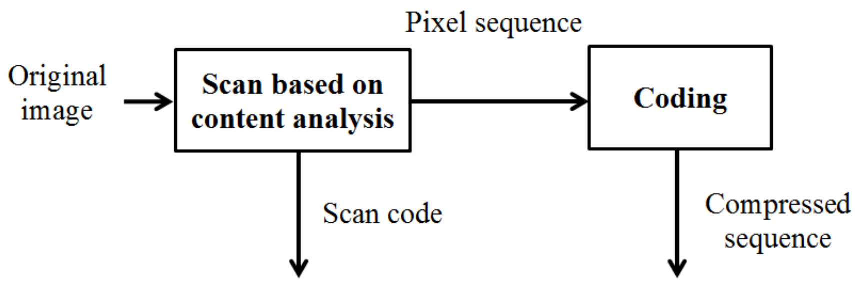

Figure 3. Adaptive Scan Model

The construction of the scan path is carried out while the evolution of the scan itself. The analysis and scanning are combined. The scanning starts from a given pixel. Next, according to considered analysis function, the next pixel is found. Then the sequence of pixels and the code of the path (additional information) will be updated. We represent this model by the following simplified algorithm:

```
Algorithm: Adaptive scan
Input:    Image (matrix of pixels)
Outputs: linear sequence of pixels
          Scan code
For pixel_index from pixel_beginning to pixel_end
     Search next pixel (analysis function)
     Updating the sequence of pixels
     Update code path
END
```

This model tends to converge to the optimal scan. However, such scan generates a considerable encoding extra cost which calls into question its efficiency. In the next, two examples will then be presented;

A. Scan Based on the Correlation Optimization

This method relies on the correlation optimization by looking for a particular scan which project image pixels with the highest similarity in adjacent pixels in the resulting pixel sequence. This scan relies on a covariance matrix – which constitutes the analysis function of this method - calculated for each block of pixels [10]. The covariance matrix indicates the level of similarity of each pixel with another. Subsequently, the one with the highest level of similarity is chosen as its successor and its position will be recorded to form the whole trajectory scan.

From the correlation point of view, this method shows high efficiency. By grouping the pixels that have a high similarity, this scan method generates a smooth signal with a relevant correlation. However, its compression performances are affected by the extra encoding cost of the additional information relative to the scan trajectory (positions of the different path points) to be transmitted.

This scan is introduced in DPCM based compression scheme in lossy image compression context. The author provides an entropy based comparison between pixel sequence generated by classical scan-line and one generated by the proposed scan where the latter shows a modest/insignificant supremacy. However, no visible quality improvement is detected in compressed images [10].

B. Scan Based on Geometric Shapes

In this method, the image is considered as a set of objects with various shapes. Thus, an appropriate SFC crosses the pixels in the main forms of the image, as long as possible before going outside. That is, the number of crossings should ideally be minimized.

As can be seen in figure 4, the Peano scan maintains locality but gives a substantial number of edge crossings. In contrast, a context-based SFC is tailored to avoid edge crossings to a considerable extent (see figure 5), resulting in a smoother pixel-sequence.

This scan method seems to be efficient for geometrically simple images. However, given an arbitrary shape, the problem of finding such a SFC is NP difficult, especially for images with complex textures [11].

This method is based on the correlation between a pixel and its neighbors. For each pixel, the scan process selects the next pixel among the three neighbor pixels depending on a specific algorithm (called Hamilton algorithm). Since three possibilities of neighborhood arise for each pixel, 2 bits per pixel are needed for the scan path encoding. Such extra cost may be penalizing to the compression efficiency [11]. On the other hand, for a given pixel, the choice of its successor among its three neighbors is not always the best choice given that some distant pixels with more relevance of similarity than the one chosen in the neighbourhood could be founded.

Compared to one based on the correlation optimization, this method shows a reduction in the encoding extra cost at the expense of less relevance in terms of correlation. Dafner shows in [11] that the encoding extra cost of the scan order exceeds the given gain for the compression of the reordered sequence which gives a negative efficiency (see table 1).

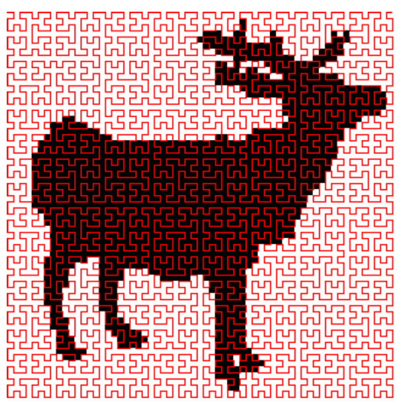

Figure 4. Illustration of Hilbert Scan

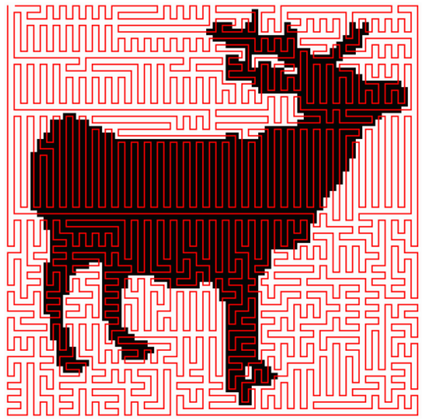

Figure 5. Illustration of the Scan Based on the Geometric Shapes of the Image [11]

Table 1. Evaluation of the Geometric Shapes Based Method

Reduction of the encoding cost	5-10% in relation to Hilbet Peano scan
Efficiency	(-4)-(-7)% in relation to Hilbet Peano scan

Globally, we can state that adaptive scans show relevant entropic propriety. They generated a smooth pixel sequences with high correlation. However, their compression performances are seriously affected by the extra encoding cost due to the encoding of the specific scan trajectory.

3.2.2. Predefined Scan Model: Separation between Analysis and Scan

Methods based on the model of predefined scan proceed in two stages (cf. figure 6). These methods start with an image analysis step in order to divide the image into different regions. This subdivision can be performed using segmentation techniques or hierarchical quad-tree subdivision according to a given homogeneity criterion. Such segmentations subsequently result in homogeneous regions. This phase aims to -by moving from a global vision towards a local vision- reduce the non-stationarities of the image. Then, the scan step consists in scanning each region with a predefined scan.

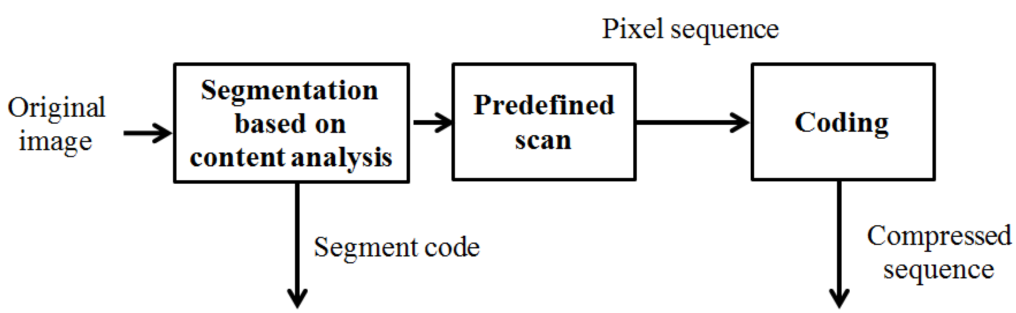

Figure 6. Non Adaptive Scan Model

This model should result in a low extra cost encoding. The predefined adopted scan seems to be efficient when applied on uniform/homogenous regions. These two points could lead to the possibility of designing of efficient scan approaches according to the definition already introduced in section 2.We present thereafter some case studies of this model;

A. Hierarchical Based Scan Method

Ziv- Bar and Cohen propose in [12] a region based scan approach. The algorithm starts with a hierarchical division based on quad-tree representation. An image can be represented by a quadtree by dividing it recursively into four equal size quadrants until a stopping condition (homogeneity threshold) is met. The splitting criterion can be the color or texture homogeneity of the image quadrant. Thus image could be represented by a tree formed by nodes and leaves. Leaves represent the final level blocks, and nodes represent the average values of blocks pixels.

The order of scan is set in a hierarchical manner according to two rules:

Thereafter the distances between the leaves and correspondent node will be calculated.

The first specifies the order of scanning between different blocks. From one block to another, the order of the scan will be based on the differences, also called distances, between leaves (blocks) average and the correspondent node value. Starting from a node, the first leave to be served is the one which presents minimal distances with the initial node. Since the distances presents, somehow the level of incoherence between the blocks, this strategy tends to group homogeneous blocks.

The second specifies the order of scan inside the blocks. Indeed, within each block, the order of scan is prefixed. Each block is scanned from top to bottom and left to right.

The encoding extra cost of this method is equal to the encoding cost of the quad-tree representation.

Associated to GIF coder, this scan method shows relative improvement compared to linear and Peano generic scans.

Table 2 gives an idea about the efficiency of this method.

Table 2. GIF Encoding Evaluation of Hierarchical Based Scan Method

Reduction of the encoding cost	5.5 % in relation to the scan line by line 3.6 % in relation to the Peano scan
Efficiency	4.3% in relation to the scan line by line 2.5% in relation to the Peano scan

B. Segmentation Based Scan Approaches

This method relies on a specific segmentation algorithm based on the pixels similarity in the image in order to locate the different homogeneous regions. Alternatively, a map showing the obtained segments will be drawn in order to reposition them later during the reconstruction of the image. The segmented regions are then scanned according to predefined paths. The sequence of pixels is then encoded. The extra cost of scan path encoding is limited to the encoding cost of the segmentation map.

Authors [14] pretend that segmentation map requires about 0.6-0.7 bit/pixel.

This method is tested for lossless compression purpose. The author provides an entropy based comparison between pixel sequence generated by classical scan-line and one generated by the proposed scan. The latter shows an improvement of about 1bit/pixel.

Moreover, this scan is introduced in DPCM based compression scheme in lossy image compression context. The proposed scan show some improvement in PSNR (2-3 db) compared to classical scan line.

However, this method introduces enormous complexity due to the segmentation phase while simplifying the scanning process. From the complexity point of view, such method only carries the complexity of the fundamental process (scan) to the complexity associated with pre-processing (segmentation).

3.2.3. Semi Adaptive Model

In this model the scan is set up by a combining a number of predefine SFC. It consists in providing a near optimal scan by selecting a suitable SFC from a dictionary of predefined scans patterns. This dictionary contains basic scans sometimes with a number of transformations (rotation, symmetry ...). Then a number of rules are established for the construction of the adapted SFC from the dictionary.

The idea consists often in dividing the image into small blocks, and then looking for the most suitable pattern for this block. Choosing the best pattern is achieved by competition, that is, to find optimal pattern, the scan process tests all patterns and keep the one which generates the bit sequence whose encoding cost is minimal. The set of patterns will after that form a compound SFC (mosaic of basic scans), giving the overall scan. Two case studies will be exposed in the next.

[16] has proposed a bit-plane processing system which utilizes an image scanning language called SCAN. The SCAN is a formal language-based two-dimensional spatial-accessing methodology which can efficiently specify and generate a wide range of scanning paths or space filling curves as it is presented in Figure 7.

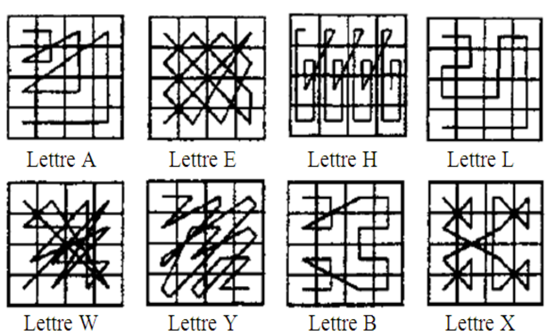

Figure 7. Example of Patterns Dictionary

First, image is transformed into an error image matrix using DPCM. Then, each 8-bit gray scale matrix is separated into its eight binary components or bit planes. Next, each bit plane is divided into equal size blocks (in the order of 64 x 64), and each of these blocks is scanned with the appropriate SCAN language algorithm, then pixels with the same binary value can be grouped together and encoded. This method could achieve good performance by utilizing a scan pattern that matches the macro-topology of the image block being processed as closely as possible. It is accomplished without a priori knowledge of the image by scanning each bit plane of each block with four different scan patterns and selecting the best results for output.

The Figure 8 illustrates the method principle.

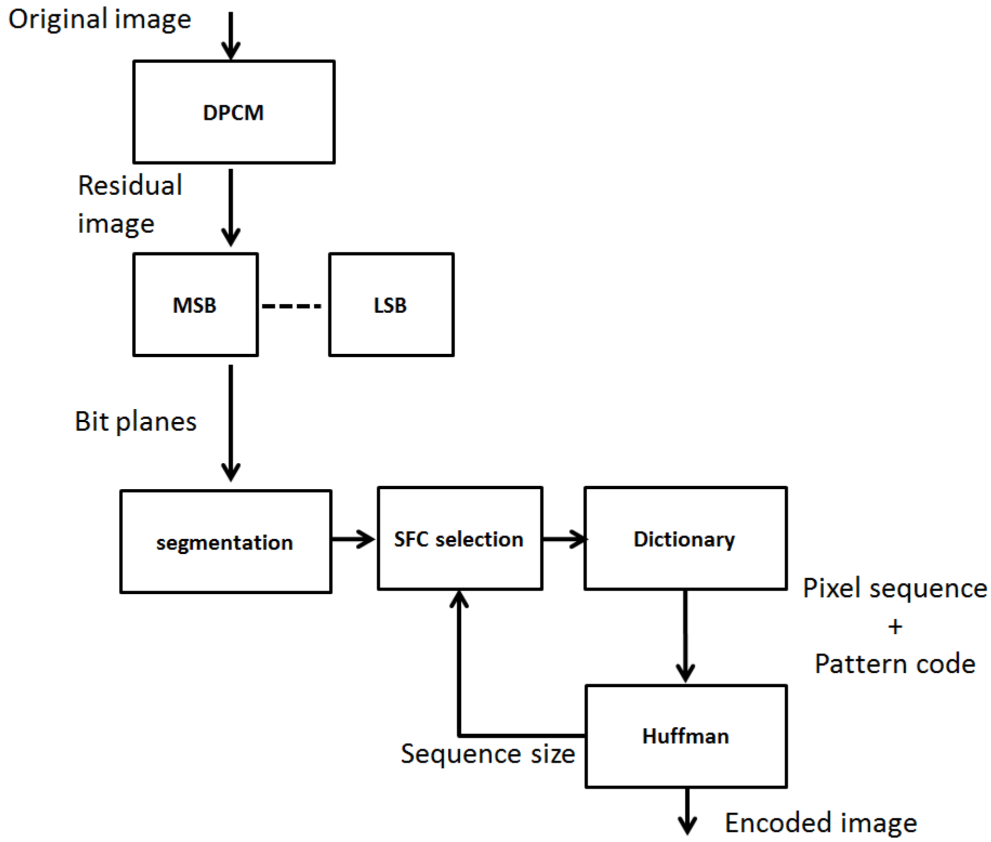

Figure 8. Semi Adaptive Scan Method: 1st Variant

The second variant adopts a strategy of block recursive splitting. (Figure 9) [17]. The splitting stops when the length of the binary code (Huffman) concerning the sequence generated by the scan reaches a minimum value set beforehand. Otherwise, the sequence is considered long and the corresponding block is divided into four.

The second variant adopts a strategy of block recursive splitting. (Figure 9) [17]. The splitting stops when the length of the binary code (Huffman) concerning the sequence generated by the scan reaches a minimum value set beforehand. Otherwise, the sequence is considered long and the corresponding block is divided into four. Thus a tree corresponding to the different scans attributed to the different levels of partitioning is constructed as shown in Figure 10 (b). An illustration of the generated scan for a binary image of size 16x16 is given in Figure 10 (a). Figure 9 (b) shows the tree corresponding to the image that will be used later to reconstruct the image. Moreover, we note that in this variant two patterns dictionaries were built, the first concerns the order of the pixels scan on in each region, the second is used for the arrangement of the different regions.

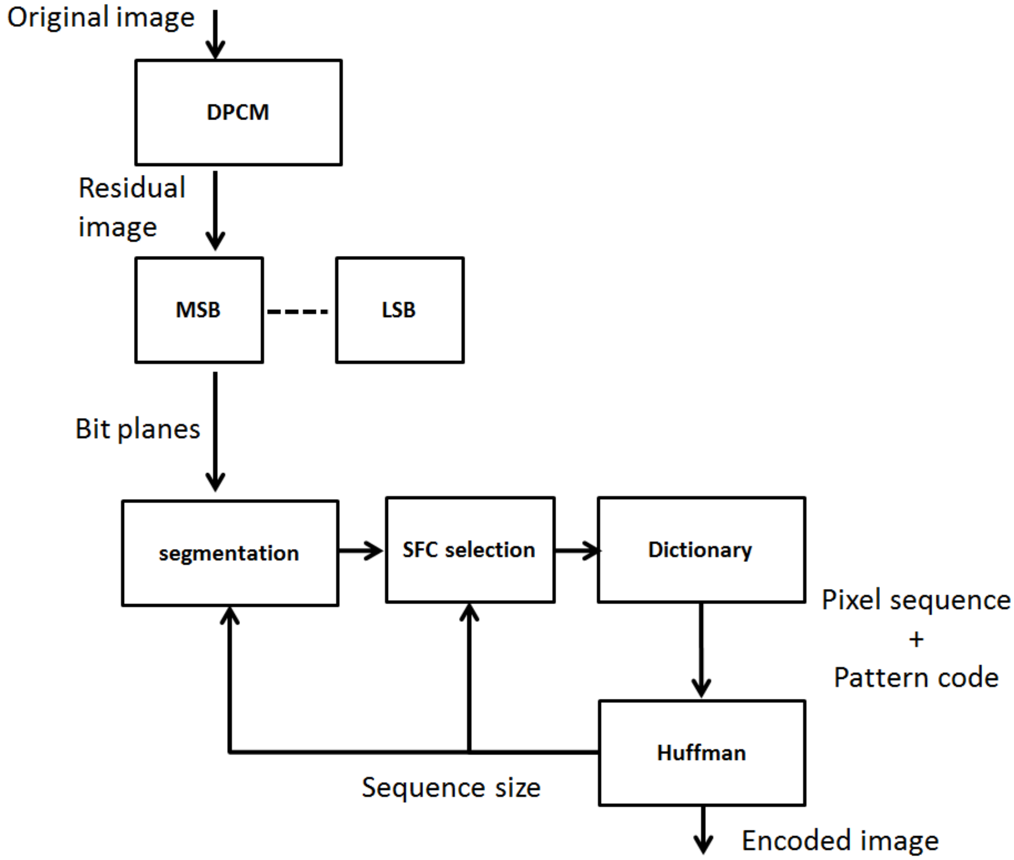

Figure 9. Semi Adaptive Scan Method: 2nd Variant

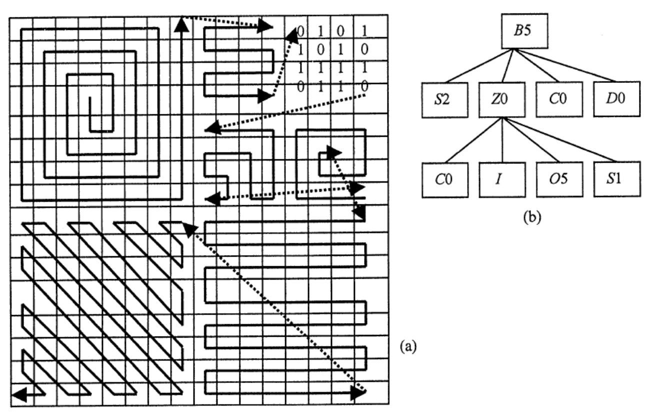

Figure 10. Example of Hierarchical Based on Scans Dictionary

This variant is applied to lossless compression and encryption of grayscale images (8 bits). It shows acceptable compression performances especially with medical images. However, it should be noted that this method is very time consuming.

In term of compression, the first variant slightly outperforms the second one. Considering Lena grayscale image (512x512), the first variant achieves 1.63 as compression rate while the second achieves 1.73.

3.3. Synthesis

Table 4 presented at the end of the paper summarizes the characteristics of different scan methods described in previous sections.

In overall, we can notice that adaptive scan methods often result in complex scan with an important additional coding cost which makes it not suitable for the compression.

Subsequently, the search for an optimal scan by seeking the similarity between pixels which are distributed anywhere in the image leads in a complex impractical scan, moreover, considering the shapes in the image that are often complex and then their correct detection is difficult seems to be impractical way to perfectly exploit the scan potential in image compression.

The idea to split the image into homogeneous regions adopted by some scanning methods described above avoids the need for complex scans. Its effectiveness depends on the nature of adopted segmentation. For example, a well-defined segmentation generates costly additional data and processing complexity.

To solve the problem of coding overhead, scan-based dictionary of predefined patterns could be an efficient solution as it leads to a near optimal scan with low extra coding cost. Indeed, the final scan constitutes a combination of basic SFCs. Thus, each used SFC is substituted by its correspondent code and no need to code the whole scan trajectory. Such method could be improved if we take into account some considerations:

First, the image subdivision into bit planes adopted in [16] and [17] is in our view irrelevant. Indeed, such a partitioning leads to the dispersion of a small variation in intensity to multiple bit planes.

Actual test results show that this methodology works very well for the more significant bit planes, but compression becomes impossible for the less significant bit planes due to the random nature of these image patterns.

Such subdivision should be kept to lossy compression context where specific quantization of less significant bit planes could be introduced.

Second, the specification of the patterns and their correspondence to the macro topology of the image constitute a big issue. Indeed, extended dictionary offers more possibility to generate a better scan, but it generates more additional data and makes the system slower as the pattern matching process have to test all the existing SFCs before selecting the suitable one such as the case for [16, 17, 21].

Moreover, it should be noted that the criterion on which basic SFCs are selected to set up the dictionary is a big question mark. Choosing geometrically complex patterns make difficult the selection of the appropriate pattern for a given region. The unpredictable character of patterns limits the possibilities to set a criterion that a pattern is considered optimal for a particular region of the image, and therefore the only option left, which was adopted in the methods we have presented, is to proceed by competition. In fact, for each region, the algorithm have to arrange the pixels according to all the different models proposed by the dictionary and code sequences generated by each model before deciding which is relevant. Such a procedure is very disadvantageous in terms of processing complexity and execution time.

In [15] an alternative that attempts to resolve such problem includes an analysis based predictive module in order to predict the direction of the pixels intensity distribution and according to that a suitable SFC that advantages such detected direction is attributed. In this method, simple directional SFCs are included in the dictionary which allows the possibility to select the best one without being forced to test all patterns.

Table 3. Summary of Adapted Scan Methods

Model	Adaptive scan methods		Predefined scan methods		Semi-adaptive scan methods	
method	Based on the optimization of correlation	Based on geometrical form	Hierarchical subdivision	Based on segmentation	1st variant	2nd variant
Correlation	Pixel similarity	Neighborhood	region	region	Bit-plane	Bit-plane region
Analysis	covariance	Hamiltonian algorithm			competition	competition
Subdivision			Hierarchical	segmentation	uniform	Hierarchical
Scan	adapted	adapted	standard	standard	Approximated by SFCs mosaic	Approximated by SFCs mosaic
Extra encoding cost	Path (position of each point of the path)	Path (Pointer on next)	Tree	Region map	Dictionary	Dictionary + tree
Lossy compression	-	Not evaluated	+	+	Not evaluated	Not evaluated
Lossless compression	Not evaluated	-	Not evaluated	+	++	++

4. Conclusion

Conceptually speaking, a scan method is able to convert a hard-to-compress signal into an easier-to-compress one by exploring source redundancies within the input signal which could be very useful in image compression. Thus, the flexibility character and the diversity of the SFCs seem to be a promising source for new image compression methods design.

Although several scan based method have been proposed in the literature, we believe that this track is still insufficiently explored.

We summarize the issues that explain the poor solicitation of the scan exploitation in image compression in three:

- The first is the discontinuity of the researches that attempt to explore this direction. In fact, the SFCs exploration seems to be a new area for many researchers who have tried to use it intuitively in different contexts including lossless and lossy compression, improving performance of some existing encoders (GIF, PNG), encryption etc. We think that the existing scan methods are closer to individual attempts in various directions than researches based around a central axis. As a result, no basic structure on which works can be chained in order to build and improve a complete image compression scheme based on the scan.

- The second issue is the additional complexity due to the analysis phase introduced with or before the scanning process.
- The third issue consists in how to ensure a benefic compromise between optimal scan and extra coding cost.

We believe that efficient use of SFCs features in image compression depends on the resolution of these three issues.

References

[1] M. Sindhu and R. Rajkamal, "Images and Its Compression Techniques –A Review", International Journal of Recent Trends in Engineering, vol. 2, no. 4, **(2009)** November.
[2] M. Khan and Y. Ohno, "A Hybrid Image Compression Technique Using Quadtree Decomposition and Parametric Line Fitting for Synthetic Images", Advances in Computer Science and Engineering, vol. 1, Issue 3, **(2007)** November, pp. 263 – 283.
[3] Y. -C. Tsai, M. -S. Lee, M. Shen and C. -C. J. Kuo, "A quad-tree decomposition approach to cartoon image compression", IEEE 8th Workshop on Multimedia Signal Processing, vol. 17, no. 6, **(2006)** October, pp. 456–460.
[4] A. Ansari and A. Fineberg, "Image data compression and ordering using peano scan and lot", IEEE Transactionson Consumer Electronics, vol. 38, no. 3, **(1992)** August, pp. 436–445.
[5] L. Velho and J. M. Gomes, "Digital halftoning with space filling curves", Computer Graphics, vol. 25, no. 4, **(1991)** July, pp. 81–90.
[6] I. H. Witten and R. M. Neal, "Using peano curves for bilevel display of continuous-tone images", IEEE Computer Graphics and Applications, vol. 2, no. 5, **(1982)**, pp. 47–52.
[7] S. Kamata, R.O.Eason and E. Kawaguchi, "An implementation of the hilbert scanning algorithm and its application to data compression", IEICE Transaction information and systems, vol. E-76, no. 4, **(1993)** April, pp. 420–427.
[8] N. Max, "Visualizing hilbert curves", IEEE Visualization'98, **(1998)**, pp. 447–450.
[9] P. T. Nguyen and J. Quinqueton, "Space filling curves and texture analysis", IEEE Intl. Conf. Pattern Recognition, **(1982)** October, pp. 282–285.
[10] Y. Matias and A. Shamir, "A video scrambling technique based on space filling curves", Proceedings of Advances in Cryptology - CRYPTO'87, Springer LNCS 293, **(1987)**, pp. 398–417.
[11] R. Dafner, D. Cohen-Or and Y. Matias, "Context-based Space Filling Curves", EUROGRAPHICS, **(2000)**.
[12] Z. Bar-Joseph, D. Cohen-Or, "Hierarchical Context-based Pixel Ordering", Comput. Graph Forum, vol. 22, no. 3, **(2003)**, pp. 349-358.
[13] R. Prăcko and J. Polec, "DPCM Application to images scanned by SFC method", Journal of Electrical Engineering, vol. 58, no. 3, **(2007)**, pp. 161–164.
[14] R. Prăcko and J. Polec, "Segmentation Based Image Scanning", Radioengineering, vol. 16, no. 2, **(2007)** June.
[15] T. Ouni and A. Lassouad, "Adapted Scan based Lossless Image compression", in proceeding of International Conference on Signal Processing, Image Processing and Pattern Recognition, **(2011)**.
[16] G. W. Drosta and N. G. Bourbakisa, "A hybrid system for real-time lossless image compression", Microprocessors and Microsystems, vol. 25, **(2001)**, pp. 19–31.
[17] S. S. Maniccam and N. G. Bourbakis, "Lossless image compression and encryption using SCAN", International Journal of Pattern Recognition, Elseiver, **(2001)**, pp. 1229-1245.
[18] J. Ziv and A. Lempel, "Compression of individual sequences via variable-rate coding", IEEE Transactions on Information Theory, vol. IT-24, no. 5, **(1978)** September, pp. 530–536.
[19] J. Ziv and A. Lempel, "Compression of two-dimensional data", IEEE Trans. on Information Theory, vol. 32, no. 1, **(1986)** January, pp. 2–8.
[20] Y. Matias and A. Shamir, "A video scrambling technique based on space filling curves", Proceedings of Advances in Cryptology - CRYPTO'87, Springer LNCS 293, **(1987)**, pp. 398–417.

[21] P. A. Pasumpon and S. N. Sivanandam, “Near Lossless Image Compression (NLIC) using Simple Arithmetic Operation with Selective Scan Order”, European Journal of Scientific Research ISSN 1450-216X, vol. 68, no. 4, **(2012)**, pp. 574-583.
[22] N. Memon, D. Neuhoff and S. Shende, “An analysis of some common scanning techniques for lossless image coding”, Thirty-First Asilomar Conference on Signals, Systems & Computers, vol. 2, **(1997)**, pp. 1446–1450, Location: Pacific Grove, CA , USA.
[23] J. Miano, “Compressed image file formats: JPEG, PNG, GIF, XBM, BMP”, ACM Press/Addison-Wesley Publishing Co., New York, NY, USA, 1999.