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Research Article

EVOLUTION AND ADVANCEMENT OF ARITHMETIC CODING OVER FOUR DECADES

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ABSTRACT

Arithmetic Coding (AC) is a form of entropy encoding used in lossless data compression. It is a well-known, state of the art technique, in which the frequently seen symbols are encoded with fewer bits than rarely seen symbols. It has been widely used since last four decades. Many researchers worked on it to improve its performance and they successfully experimented with it. This technique has also been in use in combination with other techniques to gain surprising results. In this survey paper, an effort is made to recap a number of accomplishments from 1976 to 2017 regarding Arithmetic Coding. This study provides an insight for new researchers to know how this technique evolved with time and how major achievements were made using this technique. This paper gives a comparison of AC with another well-known technique named Huffman Coding. Comparison with its contemporary counterparts shows that it is better in performance almost in every situation.

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INTRODUCTION

The goal of Multimedia data compression is to save volume of storage and pack additional data in the equivalent size space, and to reduce the time needed for communication or the time needed to transfer the data. Different compression techniques can handle different types of digital data, for example, text, images, videos etc. In literature, data compression is alternatively used term for *Encoding*, and decompression is also referred to as *Decoding*. In very short period of time, we have witnessed that amount of data produced from different resources is growing exponentially, as well as software handling this huge data has been growing, and the information to be transferred among different nodes has also been constantly escalating. Therefore, data compression technology can be appraised as a key pillar to hold the information fundament.

WHAT IS ARITHMETIC CODING?

Arithmetic coding (AC) is a statistical method of data compression that works by encoding one symbol at one time. The length of the encoded output code of every symbol can vary depending upon the probability of frequency of the symbol. Fewer bits are used to encode symbols with high probability, whereas, many bits are used to encode symbols with low probability. Using Arithmetic coding; data is compressed by representing a message into an interval of real numbers between 0 and 1. When the process begins, the range for the message is the interval of real numbers [0, 1). As the process continues to encode each symbol, the interval will be subdivided into subintervals associated to the symbol of the alphabet. That is how the range will be narrowed according to the probability assigned to that symbol. Therefore, the more probable symbols will reduce the range by less than the unlikely symbols, consequently adding fewer bits to the message. Each interval can defined perfectly by its range, A, and its left point, C. Compression performance is directly proportion to the more correct estimation of probabilities tuned by the updating process. The encoding process stops when all input symbols are processed and the value of the last C that represents the compressed code, will be transmitted to the decoder. Decoding is achieved in three steps, first, interpret C as magnitude, second, perform searching with magnitude comparison, and third, take the inverse iterative process for C. A general arithmetic coding permits a simple and fast encoding if applied to a binary alphabet. The pseudo code for arithmetic encoding algorithm is shown in Fig. 1.

The standard architecture of arithmetic encoding technique has two units: the modeling unit and the encoding unit. The modeling unit is responsible for converting the input source stream into the probability event, which is effective for encoding. Further, modeling unit is of two kinds: non-adaptive modeling and adaptive modeling. Non-adaptive modeling unit assigns a fixed probability distribution to every symbol. On the other hand, adaptive modeling unit, as the name suggests, is flexible in adjusting the probability distribution of every symbol. Adaptive model achieves superior compression results as compared to non-adaptive model. Probability of the current symbol can be adjusted by taking into account the neighboring symbols using high-order Markov statistical model in the adaptive model. After getting the probability from the modeling unit, it is provided to the encoding unit along with the symbol of every pixel.

The concept of arithmetic coding is beyond than just to replace an input symbol with a specific code. In fact, it receives a stream of input symbols and replaces it with a single floating point number as output. More bits for output will be required to replace the longer (and more complex) message, and vice versa. This output is a single number that is less than 1 and greater than or equal to 0. In order to create the output number, the symbols that are being encoded have to have a set of probabilities assigned to them. This output can be distinctively decoded to reproduce the identical stream of symbols previously used for encoding.

The use of arithmetic coding had always been limited due to its large computational complexity. In fact, after many years of its invention, it was perceived as a mathematical curiosity because the operation of additions made it slower, multiplications made it more expensive and divisions made it impractical. But today, as these operations can be performed with much more efficiency than ever before, so Arithmetic coding has become better to most of its counterparts. High storage and high transmission costs are two major factors that can be coped using Arithmetic coding. It achieves compression at greater speed without having any effect on the compression ratio. The compression performance achieved by AC might not be on a par with more sophisticated models, but it can minimize memory consumption better than its counterparts, for example, well-known Huffman method.

```
/* ARITHMETIC ENCODING ALGORITHM. */
/* Call encode-symbol repeatedly for each symbol in the message. */
/* ensure that a distinguished "terminator" symbol is encoded last, then */
/* transmit any value in the range [low, high). */
encode _symbol (symbo1, cum_freq)
                range = high - low
               high = low + range*cum _freq[symbol - 1]
               low = low + range*cum _freq(symbol1 ]

/* ARITHMETIC DECODING ALGORITHM. */
/* "Value" is the number that has been received. */
/* continue calling decode-symbol until the terminator symbol is returned. */
decode_symbol(cum - freq)
   find symbol such that
               cum_freq[symbol]  <= (value - low)/(high - low) < cum_freq[symbol - 1]
/* This ensures that value lies within the new */
/* [low, high) range that will be calculated by */
/* the following lines of code. */
               range = high - low
               high = low + range*cum_freq[symbol - 1]
               low = low + range*cum_freq[symbol]
return symbol
```

Fig. 1. Pseudocode for Arithmetic Encoding Algorithm

It represents information at least as compactly as Huffman's technique and sometimes considerably more so. It has enabled greater reductions in bit rate than achieved by the optimal Huffman's technique, towards the entropy limit of a source. Its performance is optimal without any need of blocking input data. It supports a clear partition between the model that represents data and the encoding of information with respect to that model. Along with this, arithmetic coding has the ability to dynamically track the changing probabilities of a source. It can easily accommodate adaptive models and is computationally more efficient.

WHAT IS ADAPTIVE ARITHMETIC CODING?

The simplest kinds of models are fixed Models in which frequencies of symbols are fixed. In contrast, Adaptive models are those models that have varying frequencies of symbols seen so far in a message. Initially all frequencies might seem to be the same, but as each symbol is seen in the message with time, and frequencies are updated, the changing frequencies can be observed. Models of encoder and decoder can work in-line only when both use the same initial values, and the same updating algorithm. The encoder receives the next symbol for encoding and updates its model; the decoder identifies the symbol according to its current model and then updates its model.

EVOLUTION OF ARITHMETIC CODING

Arithmetic coding can be traced back to Elias in the early 1960s (see [l, pp. 61-621]) by Abramson, N. in his book "Information Theory and Coding" McGraw-Hill, New York, 1963. This textbook contains the first reference to what was to become the method of arithmetic coding (pp. 61-62). Practical techniques were first introduced by (1) and (2). This was an early exposition of the idea of arithmetic coding, but lacking the idea of incremental operation. (3) gave another early exposition of the idea of arithmetic coding and developed it further as a practical technique for data representation.

In the early years of invention of arithmetic coding, many authors comprehended the basic idea and introduction of the technique. In his paper, (4) gave a full introduction of Arithmetic coding by writing that this technique takes a string of data symbols from source and maps it to a code string. The original source data can be recovered from the code string. Arithmetic operations are performed on the code string by the encoding and decoding algorithms. In one recursion of the algorithm one data symbol is handled. A simple model is the memory-less model, where the data symbols themselves are encoded according to a single code. He also talked about another model, i.e., the first-order Markov model that uses the preceding symbol as the context for the following symbol.

Next section tells a brief history of Arithmetic coding technique in a chronological order.

FROM 1989-1999

In the beginning, many authors presented overview of the Arithmetic coding like (5) presented a summary of the technique, in particular Binary Arithmetic Coding (BAC): he introduced a number of basic concepts and considered in his paper both the coding and decoding algorithms with the help of an example. He described a particular application of BAC, namely the coding of discrete cosine transform (DCT) coefficients, at 17Mbit/s and 34Mbit/s. He described that BAC is a sub-class of arithmetic coding in which events are limited to a binary rather than multi-symbol alphabet.

He compared the results of simulations carried out at BTRL, along with results produced by more traditional Huffman-based, Variable Length Coding schemes. He also presented problems associated with the implementation of arithmetic coding over noisy transmission mediums. He showed paper that AC out-performed the best of the alternative schemes in all cases: this performance advantage varies, according to the source material, from 3-7%. Author studied BAC as an alternative to traditional Huffman based VLC techniques for application in high bit rate CODECs. He also mentioned the concept of context in this paper. He wrote that the context refers, in some way, to the neighborhood of a particular event. In the end, author redirected the attention of the reader to an area of research, that is, error control for an arithmetic code string.

In 1991, (6) introduced a locally adaptive model for AC that used a limited number of preceding symbols to model the cumulative density function of the arithmetic coder. The method as a variable length code was applied to compress videos, and it outperformed the first-order entropy of the compressor. He further stated that the "Huffman code is a practical VLC, but its performance is limited to the integer representation of the assigned bits. Thus Huffman coding is always inferior to entropy". Arithmetic coding as a practical VLC was introduced a decade before with performance close to the entropy. In his paper, author presented a method of AC that could shrink the bit rate of the coded images even below than first-order entropy. It was able to achieve this rate by reducing the buffer size. That is how its performance became superior to entropy. The most favorable buffer size was of around 64 samples for both 8 x 8 and 16 x 16 Peano blocks. However, further contracting the buffer size, adversely affected the efficiency of the coder.

Researchers put their efforts to improve AC so that to minimize the time required without giving up much on coding efficiency. Table Lookup approach was one of those efforts in practice, known as quasi-arithmetic coding. It was considered as generalized form of Huffman coding. This technique considered the intermediate intervals computed by the coder as states of the coder. Using just a few states can often improve efficiency much more than that of Huffman coding. By summing up, efficient parallel lossless encoding and decoding of images was practicable using Huffman coding and more amazingly, a version of arithmetic coding as well.

(7) proposed an algorithm based on the hierarchical MLP (Multi-level Progressive) method, used either with Huffman coding or with a new variant of AC called quasi arithmetic coding. They designed a general purpose algorithm for encoding and decoding that could use both Huffman and AC techniques. They applied the algorithm to the problem of lossless compression of high resolution grayscale images. They showed that high-resolution images can be encoded and decoded efficiently in parallel. The coding step can be parallelized. As they experimented with both techniques, when Huffman coding was not enough, the experiments were switched to AC.

With the passage of time, due to better performance, adaptive BAC gained importance that Joint Bi- level Image Experts Group (JBIG) of IS0 and CCITT stipulated an adaptive binary arithmetic encoder-decoder for the lossless compression of bi-level images. Keeping in view the importance of the technique, (8) presented a JBIG arithmetic coder-decoder chip in 1992. The chip was designed to operate in two modes, i.e. either encode or decode, for half-duplex operation. Irrespective of the compression ratio and the mode of the chip, five clock cycles were required to process one bit of raw (uncompressed) data.

IBM's Q-coder works on mathematical operations, such as time consuming multiplications and divisions, but later on these operations were replaced by additions, shifts and low-order bits were ignored by (9). Later on, many researchers put on their efforts to improve the technique, such as (10) described a different approach to examine arithmetic coding in their study. (11) recalled the concept of table-lookup version of AC, a quasi-arithmetic coder. They mentioned that the method was still totally reversible; and also that by using reduced precision method just changes the average code length. The proved that reduced-precision arithmetic version had an insignificant effect on the compression achieved. They then proved that implementation can be further speed up by use of parallel processing. They discussed the role of probability models and specifically they addressed "Zero frequency problem" and "locality of reference" in detail. They put emphasis on probability model and stated that "To obtain maximum compression of a file, we need both a good probability model and an efficient way of representing (or learning) the probability model", because AC almost always gave better compression but there was no direct correspondence between the input data set and bits/groups of bits in the encoded output file. A mathematical coder works in association with a probability modeler to estimate the probability of every event that is likely to happen at each point in the coding. The probability modeler simply generates probability distribution for the data items without knowing the process of generating the data. The probabilities generated by the model do not always have to be particularly accurate, but the compression rate would be better if the probabilities are more accurate. The whole process will give opposite results by expanding the size of file instead of compressing it if the probabilities are inaccurate or even less accurate. They discussed that small errors in probability estimates can increase code length, but this issue could be solved by introducing controlled approximations into the arithmetic coding process, without appreciably reducing compression performance. They concluded their study with the outlook on the comparative advantages and disadvantages of AC. They pointed out two main advantages for statistical data compression, one is its optimal performance for a stochastic data source where probabilities are accurately known, and the other one is its innate separation of coder and modeler. To make arithmetic coding technique fully optimal, a different version quasi-arithmetic coding method was well known, that used table lookup as a low- precision alternative to full-precision. Arithmetic coding provided optimal compression, but its slow execution was problematical. For this problem, quasi-arithmetic version replaced slow arithmetic operations like multiplication and division by table lookup to make it fairly fast, even when the probabilities were close to 1 or 0. The main worth of arithmetic coding was that it achieved maximum compression in conjunction with an adaptive model.

AC is undoubtedly a competent entropy coding technique for compression of images and text. It is also appropriate for one-pass adaptive coding because of its intrinsic division of encoding and modeling units. But the major downside of the original algorithm is its requirement of multiplication operations. To solve this problem, many researchers presented variety of AC algorithms that are multiplication free, to make it well suitable for VLSI implementation for binary alphabets and for multi-alphabets. (12) first presented a performance analysis for the multiplication free arithmetic codes. They considered the relationship of compression efficiency, code space assignment, selection of renormalization interval and sub-intervals for approximations. Then they studied the consequence of trimming and rounding off the precise interval width at each stage. They concluded their study by showing that there will be no more practical multiplication free arithmetic codes.

After two years of efforts, (13) succeeded to derive a whole family of multiplication free arithmetic codes that can accomplish the best coding efficiency and can be used for random size alphabets. They presented a performance analysis for the multiplication-free arithmetic codes by bearing in mind the relationship between code space assignment, subintervals for approximations, selection of renormalization interval, and compression efficiency. They also presented absolute tradeoff between the complexity of operations and compression efficiency of the coding algorithms.

Since its birth, AC gained importance due its efficient coding method. There are two main factors of its efficiency. First, it is capable of encoding data strings using both fixed and adaptive models, and second, it is efficient enough to accomplish entropy bound. In fact, faster adaptive models being computationally efficient can achieve even greater compression rate. Although AC is in use for compression of binary and gray scale images and it has also been preference in a number of standard schemes for encoding images as an entropy encoding technique, but the main problem arises for most arithmetic coders while using multilevel alphabets. Multilevel alphabets involve larger complexity because the probability of every input symbol needs to be stored and updated. Considering this, (14) presented a VLSI implementation of an arithmetic coder for multilevel images. Their novel scheme to store and update the probabilities of input symbols cutback the hardware complexity and the total area by decreasing the number of registers and adders, in contrast to the conventional ones. The ensuing chip had an area of 31 mm^2 and operating frequency of 39 MHz. Their proposed improvements in the architecture of the coder can also be implemented in the design of the decoder, thus reducing the hardware complexity.

Keeping in mind the computationally expensive operations in AC algorithm, a number of approximate methods that were assumed to substitute the multiplication or division operations by less expensive shifts and addition operations were presented to cut down the computational complexity. Less precise probability estimations and the complexity in terms of hardware implementation are the shortcomings of technique, therefore (15) came up with fuzzy reasoning and gray prediction to cope with the problem of probability estimation. They emphasized that the system behavior can be simplified by using straightforward "if-then" relations (or fuzzy control rules) as an alternative of complex mathematical operations. Since control rules are more natural to take into account the qualitative aspects of human knowledge, therefore a fuzzy system can give desired output in the form of control actions using fuzzy inference process. They presented a new division-free adaptive BAC method, suitable to be implemented by VLSI technology. They adopted a binary order fixed context modeler that used the preceding binary symbols as the context to get better compression efficiency, compromising the extra storage space. The adaptive probability estimator could compute estimated probabilities more efficiently and precisely, improving the compression efficiency of the proposed method. They used table lookup method to construct an adaptive probability estimator to reduce the complexity of hardware implementation. Fuzzy gray tuner could dynamically determine the variance in probabilities. They concluded that hardware implementation of an adaptive arithmetic coding method that uses a fuzzy gray tuner to compress online data is more simple and suitable and can attain high coding throughput. In the end they compared their method with other methods and found out satisfactory compression results of their method with all kinds of data they used.

As we know that coder and source modeler are separate in arithmetic coding technique, therefore, an arithmetic coder can comply with any model providing sequence of event probabilities. This is important to note because sophisticated models providing more precise probabilistic model of the input data play vital role to obtain large compression gains. Moreover, adaptive data models used with arithmetic coding technique achieve better compression with any kind of source data. Adaptive behavior is particularly functional with sources, such as images, that are generally not statistically stationary. In this context, another effort to improve the method was done by (16). They proposed a novel adaptive AC method that used dual symbol sets called the Dual Set Arithmetic Coding (DSAC). Dual symbol set consists of a primary set that had all the symbols more likely to appear in the near future and a secondary set that had all other symbols. The primary set is the default symbol set. If the coding process doesn't find the current symbol in primary set then it searches in the secondary symbol set. Primary symbol set has to be updated by shifting symbols in and out based on the estimation of the likelihood of their occurrence in the near future by using recent observations. Their method can be implemented in its simplest form by assuming that those symbols are highly likely to appear in the near future that had appeared in the recent past. Therefore primary set was always filled with symbols that had happened in the recent past. Symbols moved dynamically between the two sets to adjust to the local statistics of the symbol source.

They then discussed several variations of DSAC. They stated that Markov models could be added to DSAC same as the Markov models work with normal AC. In another variation, the frequency of the escape symbol ESC was chosen to be greater than one. By linking a greater frequency count to ESC, compression rate of coding the extra symbol ESC was reduced at the cost of tricking the probabilities of the symbols in the primary set. Their experiments showed that the proposed method can even outperform the AC when used in combination with wavelet-based image coding. The proposed work performed better for sources, such as images, distinguished by large alphabets having skewed and highly non-stationary distributions. They performed theoretical and experimental analysis and comparison of the proposed method with other AC methods. Their experiments showed that in various perspectives, e.g., with a wavelet-based image coding scheme, proposed method gave better compression than the conventional AC method and the zero-frequency escape AC method.

MAJOR OUTCOMES ARE AS FOLLOWS:

1. Performance became superior to first-order entropy by reducing the buffer size. Buffer size was reduced by using a limited number of preceding symbols to model the cumulative density function of the arithmetic coder that could shrink the bit rate of the coded images even below than entropy. The most favorable buffer size was of around 64 samples for both 8 x 8 and 16 x 16 Peano blocks.
2. A JBIG arithmetic coder-decoder chip was presented.
3. Table-lookup version of Arithmetic Coding as a quasi-arithmetic coder was developed.
4. A whole family of multiplication free arithmetic codes that could achieve the best coding efficiency and could be used for random size alphabets was discovered.
5. A VLSI implementation of an arithmetic coder for multilevel images was presented.
6. A new division-free adaptive binary arithmetic coding method was presented by using fuzzy inference process.
7. The Dual Set Arithmetic Coding (DSAC) was presented that used dual symbol sets, i.e., a primary set that had all the symbols more likely to appear in the near future and a secondary set that had all other symbols. The primary set is the default symbol set.

FROM 2000-2010

CAE (Content-based Arithmetic Coding) algorithm is used to compress shape information in the MPEG-4 standard. But CAE has few problems related to it. One of the few problems is the high rate of memory access. To build content for each pixel, several neighboring pixels are used to predict the probability, that's how each pixel is used several times while encoding/decoding process. When the pixel data is directly loaded from the memory, it results in the high memory access rate. To work on this problem, (17) proposed a competent design for the CAE in binary images. They used line buffers and barrel shifts in their proposed architecture. This design was able to achieve high efficiency and flexibility for a variety of "content" and different block sizes. In the architecture, memory access time was reduced by using row and column line buffers. Multiplication is the second problem of CAE algorithm obstructing the real-time implementation of the algorithm. But due to the growth of VLSI technology, it is now achievable for real-time applications to put in practice the arithmetic coder with multiplier. To cater the third problem of CAE algorithm, that is the difference of INTRA and INTER CAE in MPEG-4 authors proposed a new design with barrel shifters and line buffers. It was a more configurable architecture than CAE. It can be used for INTRA or INTER shape coding in MPEG-4 video standard.

Their architecture comprised of two units: modeling unit and coding unit. Modeling architecture offered two advantages; first, the modeling unit was configurable and could handle different widths of BAB including 16x16, 8x8 and 4x4. Furthermore, architecture was easily modifiable for the BAB of width larger than 16. The only alteration to the design was to use larger size line buffers. Secondly, the modeling unit was composed of three row and two column line buffers making it more efficient by reducing the memory access rate and the requirement of memory bandwidth. In addition to the modeling architecture, they proposed a 16x16 multiplier coding architecture compatible with MPEG-4 CAE algorithm.

AC has proved to be versatile and effective, but owing to the truth that arithmetic encoding is slower than Huffman encoding, adaptive variants of AC have gained much importance. The performance of arithmetic coders is greatly dependent on the estimate calculated by the probability model used by the coder. Therefore, if the statistical properties of the input are precisely reflected by the probability model then the arithmetic coding will draw near to the entropy of the source. A method that uses adaptive estimation of the probability is better than a non-adaptive method. It gives better insight to the "true" statistics of the data. A shortcoming of adaptive AC is that it doesn't consider the high correlation between adjacent pixels. To improve this drawback, a model is updated more than once for every new coefficient to be encoded making the probabilistic model more adaptive to recent pixels, consequently more effective. (18) proposed a fresh technique for the implementation of context-based adaptive arithmetic entropy coding. They developed the method for an appropriate selection of context for AC by predicting the value of the current transform coefficient, employing a weighted least squares method. Their technique was to use weighted/unweighted least squares method to calculate the weights used to approximate the magnitude set of the current coefficient, based on the context, i.e., selected set of magnitude sets of pixels previously coded. Experiments conducted by the authors showed that using weighted least squares algorithm led to the better results, and consistently outperformed the entropy coder.

Entropy coding, generating variable length codeword (VLC) is a foundation of any data compression design, though VLCs are very susceptible to channel noise. Methods were developed to cope with noise sensitivity by setting up an error correcting code or by introducing dedicated patterns in the chain. A lot of work has been published on the design of codes with better synchronization properties. AC continued to gain recognition in practical systems including JPEG2000, H.26L and MPEG-4 standards. (19) addressed the issue of robust decoding of arithmetic codes. They used Bayesian formalism to analyze variables and their dependencies used in AC. That's how they were able to provide a suitable framework to design a high error-resilient soft decoding algorithm. They also described a simple and efficient pruning method to keep the complex estimation within a realistic range. They then tested their models and algorithms with widely used context-based AC technique. Their theoretical and experimental investigation with real images encoded with JPEG-2000 gave satisfactory results showing that their model can produce high error resilient performance with real time sources.

Rapid increase in the development of data intensive applications created a large gap of improvement in data compression technology. Storage and transmission of floods of data require highly developed and advanced systems. For the speedy transmission of data, many data compression techniques have been developed, among which AC is one of the best and successful techniques. The compression rate achieved with AC depends greatly on the accuracy of the estimated probabilities of symbols. Higher order context models used to estimate symbol probabilities are eminent to obtain greater accuracy, but at the same time, these models add up to the complexity of implementation of the system. Therefore, hardware performance of statistical techniques is restrained to simple binary alphabets limiting the speed of implementation. Parallel scheme of implementation is one noticeable technique to speed up any algorithm. (20) proposed a scheme for multi-alphabet AC using parallel pipelined implementation. Consequently, execution of encoding and decoding can be done in a parallel-pipelined manner. They compared the compression performance of their proposed architecture with one of the existing serial implementation in terms of compression ratio and execution speed. Double the speed of implementation with comparable compression ratio was observed with their proposed implementation. Hardware of the respective modules was also greatly simplified by their proposed architecture.

AC can achieve better compression than its contemporary techniques but its complexity remained a hurdle in its wide use for media representation. To cope with this problem realistically and practically, arithmetic coders started dealing exclusively with binary alphabets: because of its computational simplicity, and in addition, feasibility of using higher-order context. (21) introduced, in one of their study, a novel memory-efficient, quasi renormalization technique that notably outperformed the renormalization method used by the M coder or any other coder utilizing the follow-on procedure. They used table lookups in their technique instead of time consuming operations (the branching operations) akin to the quasi-coder put forth by Howard and Vitter. The quasi-arithmetic coder is the best ever BAC because of table lookups as a substitute of all arithmetic operations, interval subdivision and renormalization. Merely table lookups are required to encode each bit, since all calculations are done in advance. Their scheme yielded equivalent speed as the quasi-arithmetic coder, using much less memory. They focused only on the coding part of the AC technique. The primary principle of their idea was to limit the accuracy by permitting only small number of states; thus making the number of states small and the table-based AC feasible by representing the full interval [0, 1) with [0, N) using integer arithmetic.

Adaptive AC has gained attention of many researchers, and a lot of work has been done to make it even better. This encoding technique is part of the most contemporary video compression standards. Algorithms of adaptive arithmetic encoding based on "sliding window" are broadly known. The idea behind sliding window is that buffer keeps N preceding encoded symbols, where N is the length of buffer. When all symbols are encoded, the buffer contents are moved by one place, thus sparing one location in the buffer. A new symbol is inserted to the free cell and the earliest symbol is removed from the buffer. Due to the manipulation of buffer contents, this buffer is known as "sliding window". Accurate evaluation of source and fast adaptation to dynamic statistics is one of the advantages of the "sliding window" technique. On the other hand, memory consumption due to the space required storing of window in encoder and decoder memory is a serious question about this technique. There are algorithms that match "sliding window" performance by taking into account the idea of window just for recount of symbols so there is no need to store it in memory. Based on this concept, (22) proposed an algorithm named "Virtual Sliding Window". Their method was adaptive method to estimate the probabilities of ones at the output of binary non-stationary sources. They proposed this algorithm as an alternative for Context-Based Adaptive Binary Arithmetic Coding (CABAC), an entropy encoding design of H.264/AVC standard used for video compression. They practically applied the idea of "virtual sliding window" in their proposed method. They compared their method with the probability estimation technique used in CABAC. The compression rate obtained by their technique was better. It achieved compression gain by allocating specific window lengths to different context models based on statistical properties of corresponding source. They also stated that complexity of implementation of Virtual Sliding Window was not more than CABAC implementation. They also suggested that specific and varying window lengths during sequence encoding can improve the performance of VSW.

AC has been developed tremendously by many researchers since its invention and it is in limelight for contributing greatly into high encoding efficiency. Previously, Huffman encoding technique was the only better choice of image and video coding standards such as JPEG, H.263, and MPEG-2, but recently, AC technique gave a competition to its counterpart techniques due to its performance, therefore many modern generation standards including JPEG2000 and H.264 are utilizing the technique.

Although AC is exceptionally competent technique, as traditionally implemented, but at the same time, it is not particularly secure. Consequently, in recent years, compression and security by AC has gained importance because of the growing consumption of compressed media files by a number of applications such as the Internet, digital cameras, and portable music players, and concurrently, the emerging need to offer security of the data contained by these compressed files. When there are both goals to achieve, that is, compression and security, simple method is to use a conventional arithmetic coder along with an encryption method such as the Advanced Encryption Standard (AES). This approach can surely achieve both of the goals, but taking advantage of the added design flexibility and prospective computational simplicity that is obtainable if the encoding and encryption are performed together, then conventional approach is unsuccessful.

The subject of improving the security of AC technique has received comparatively less interest in the literature. Keeping this issue in mind, (23), presented a tailored idea that offered both encryption and compression simultaneously. They specifically considered the objective of encryption, and proposed an Interval splitting AC technique. According to their idea, the uninterrupted intervals related to each symbol in conventional arithmetic coder, could be split based on a key that is known to both the encoder and decoder. That's how their idea removed the restriction of continuous intervals of corresponding symbols. As an alternative they used a generic limitation i.e., sum of lengths of one or more than one intervals linked with each symbol must be equivalent to its probability. Their work aimed to present an AC scheme that was safer against selected plain text violation. Their system utilized an arithmetic coder using which the length within the range [0,1) assigned to each symbol was preserved on the whole, however, the customary supposition of a single continuous interval used for every symbol was eliminated. Furthermore, input/output of the encoder was passed through a sequence of permutations. A system with an exponential increase in security was constructed using their idea of interval splitting inside the arithmetic coder and permutations sequence on input/output. The compression was carried out by the interval splitting arithmetic coder. Their system on the whole offered encryption and compression simultaneously, with a negligible compromise on coding efficiency as compared to conventional method. They stated that achieving security for sequences of practical length, the cost of efficiency was insignificant. Although their focus was on the static binary cases for the cause of simplicity, but the proposed method could also be used for m-ary and/or adaptive arithmetic coding.

AC technique is well-accepted and broadly used data compression technique for multimedia and text compression as well. Many studies in the literature have revealed that the compression ratio of AC can further be enhanced by converting multi-symbol alphabets to binary alphabets and then making use of the principles of Bayesian estimation. QM-coder is the simplest implementation of the binary AC technique given that it only requires simple and easy operations like subtraction and shift to estimate the probability intervals. (24) proposed a novel AC idea based on the conversion of multi-symbol alphabets to m-ary alphabets instead of just binary alphabets, and then using principles of Bayesian estimation to calculate the probabilities. The idea was to convert the multi-symbol alphabets of a given model to m-ary alphabets where the range of m is from 2 to N (N is the number of symbols in the original alphabet), then each m-ary alphabet of the altered input was arithmetically encoded by making use of conditional probabilities calculated by Bayesian formula.

They performed experiments using five grayscale images of resolution 512   512. They treated 256 possible pixel intensities of grayscale images as different symbols in the alphabet. Standard adaptive arithmetic coder was used to compress those images. Each pixel value was then converted to a codeword of base-m. Test images were compressed with m-ary arithmetic coder using different values of m.

The results achieved were really satisfactory. According to their observation smaller values of m showed improved compression ratio, and as soon as value of m reached 4, compression ratio settled down rapidly and then changes in compression ratio became insignificant with m greater than 4. Another observation was that the maximum possible value that m could work with was the size of the original alphabet N.

Entropy encoding together with quantization and transformation can considerably reduce the size of the data. For any typical multimedia coding, entropy encoding is meant to be a bit assigning and lossless compression module. Well known conventional entropy encoding methods are Huffman encoding and Arithmetic encoding applied in JPEG and MPEG coding standards. The AC is more intricate than Huffman encoding when it comes to implementation part. Entropy encoding algorithm works by ranking the input symbols according to their frequency of occurrence and then encoding them such that the less number of bits are assigned to symbols with high frequency and vice versa.

(25) developed a novel entropy coding technique offering higher compression ratio with minimized computational complexity. In their proposed algorithm, they solved the problem of error propagation by defining a group number as an indication for the decoder to pick the suitable number of bits for decoding. Number of bits and groups were allocated based on the frequency and coded effectively. The recursive property of their proposed encoding algorithm was helpful in choosing the suitable bit-rate according to the available channel band width. They conducted experiments on several multimedia data such as text, image, audio and video sequences. Their

proposed algorithm outperformed the contemporary entropy encoding algorithms in all respects such as size of compressed file and time of encoding/decoding. They minimized the complexity of tree construction at the encoder side and restoration of tree at the decoder side as in the Huffman coding. In their proposed encoding technique, the computational complexity was comparatively less than the AC. The results after experiments demonstrated that the proposed entropy encoding technique exhibited the same PSNR quality as Huffman and AC. The results for encoding and decoding times showed that the proposed algorithm was comparatively faster than AC. The proposal was more suitable for multimedia applications.

(26) presented a short speculative explanation of the standard predictive adaptive AC technique. They discussed the use of AC in one of its most common form: the predictive and adaptive form. They stated that although these features of AC were previously identified, but the literature discussing both of them was fairly hard to find; therefore they did an effort to present both aspect of AC, that is, predictive and adaptive. Their aim was not about compression efficiency but they wanted to demonstrate different ways of using AC processes in both parametrical and non-parametrical model selection problems.

They also discussed lossless and lossy encoding methods for images. The stated that lossless techniques that are using a mix of fixed-length encoding and AC are providing better compression results as compared to those with separate models. These techniques also play an interesting role in the realm of statistics as it offered a data-driven method for the non-parametrical histogram selection problem. They acknowledged that a good selection of prediction model can lead to better compression results. They took a closer look at the resulting code-length. They reader can find a comprehensive study about predictive and adaptive aspects of Arithmetic Coding.

In order to comprehend lossless and adaptive compression, (27) proposed a lossless adaptive distributed arithmetic coding (LADAC) by using the method of EOF (end of the file) and the adaptive encoding. In their proposed method, LADAC, encoding/decoding modules could work at the same time instead of working one after the other. They also designed encoder-driven method in place of decoder- driven without having a feedback channel. Experiments conducted by them showed enhanced results. LADAC gave better compression rate with less complexity than typical conventional lossless distributed arithmetic coding (LDAC), especially for the asymmetric source. Since LADAC adopted the method of End Of File and adaptive encoding, therefore eliminated the setback between the contiguous sub-blocks giving encoder and decoder the potential to work concurrently rather than working alternatively which is quite significant for practical applications.

(28) presented application research areas of AC. They discussed advantages and disadvantages of the techniques and various other factors for the interested readers.

They stated that the storage capacity of computers and transmission speeds are growing at an unbelievable speed, but still it is an area of attention for researchers, and they are making continuous efforts to improve the compression technology so that more amounts of data can be handled more efficiently and effectively. As we know that it can achieve compression ratio up to the entropy of the source, and there are no identified methods offering the average ratio better than the entropy, therefore arithmetic encoding is optimal till this day. Arithmetic coding technique is relatively fast in performing calculations utilizing less memory than Huffman coding technique, and on top of that, it is comparatively straightforward and easy to deploy in the applications. Therefore this technique is more frequently used to compress data. They highlighted that the two imperative issues related to AC are: how to effectively save a cumulative count, and how to implement the encoder speed as quickly as possible.

MAJOR OUTCOMES ARE AS FOLLOWS:

1. A competent design for the content- based arithmetic coding in binary image was proposed in 2000, line buffers and barrel shifts were used in the proposed architecture.
2. Bayesian formalism was used to analyze variables and their dependencies used in AC, so that a suitable framework to design a high error-resilient soft decoding algorithm could be provided.
3. A scheme for multi-alphabet AC using parallel pipelined implementation was proposed.
4. A novel memory-efficient, quasi renormalization technique was presented that notably outperformed the renormalization method used by the M coder or any other coder utilizing the follow-on procedure.
5. An algorithm named "Virtual Sliding Window" was presented in 2006. The method was adaptive in its nature to estimate the probabilities of ones at the output of binary non-stationary sources. The algorithm was an alternative adaptive technique for Context-Based Adaptive Binary Arithmetic Coding (CABAC). The idea of "virtual sliding window" was practically applied first time.
6. A tailored idea that offered both encryption and compression simultaneously was proposed.
7. A novel arithmetic encoding idea based on the conversion of multi-symbol alphabets to m-ary alphabets instead of just binary alphabets, and then using principles of Bayesian estimation to calculate the probabilities was presented.
8. A novel entropy coding technique offering higher compression ratio with minimized computational complexity was developed. The problem of error

propagation was solved by defining a group number as an indication for the decoder to pick the suitable number of bits for decoding.

FROM 2011-2019

JPEG2000 has become the most wanted and extensively used in aeronautic, military, medical industry and so on because of its ability to keep good visual effect even after high compression of images. Its quality to support lossy and lossless data compression, multi-resolution progressive transmission, region of interest coding and random access of code-stream makes it an explicit choice for many applications. With the advent of Internet of Things (IOT), fluent and smooth video transmission particularly in wireless settings has become critical and vital. JPEG2000 has proved itself as one of the best choices for video transmission in the wireless settings with characteristics of multi-hop and low data rate. But due to the use of Arithmetic coder for entropy encoding in JPEG2000, performance of the whole JPEG2000 encoder has been restricted because of heavy loop-iterative operations. Concerning this problem many researchers has put forth their studies from the algorithms to the hardware architecture. (29) designed a JPEG2000 Arithmetic Coder using Optimized Renormalization Procedure. They proposed an efficient and competent algorithm for the renormalization procedure, enabling the whole arithmetic coder to execute in succession, that is how shrinking the computation complexity and making the implementation on hardware easy.

Besides, they also presented the hardware architecture for their proposed algorithm that had the ability to encode a pair of CX/D only in one cycle without any complex pipeline or complicated control, well improving the system throughput. It was observed that the system clock rate could be synthesized into 79.836MHz, and the throughput was 79.836Msymbols/s. They optimized the performance of their proposed work with respect to two characteristics: first, the system clock rate was comparatively less, and second, they made the algorithm compatible and well suited for the dual-symbol processing. They suggested that if such optimizations can be recognized, throughput of the system can further be enhanced.

It is hot area of research to combine the compression and encryption to develop more sophisticated multimedia applications. Three methods can be summed up for achieving compression and encryption at the same time.

1. Use a conventional data compression technique for compressing the data, and then encrypting the already compressed multimedia data by using a traditional Data Encryption Standard (DES) or the Advanced Encryption Standard (AES). This method is unsuitable for real-time multimedia applications because of exceptionally high computational complexity.

2. Cut down the computational complexity significantly by the selective encryption approaches, that is, encrypt only the important segment of the multimedia data.
3. Modify the compression techniques, such as the Huffman Coding or the arithmetic Coding, so that these techniques have innate functionality of encryption.

(30) studied the third approach and presented a new design to fine tune the sizes of intervals linked with the selected symbols determined by a secret key. They designed a method to construct the key vector using Pseudo-Random Bit Generator (PRBG) and the Secure Hash Algorithm (SHA-256). Encoder and decoder must have the knowledge about each bit of the key vector. The source intervals related to each of the different symbols were required to be attuned before encoding the new symbol. They claimed that, without compromising on coding efficiency, their technique has offered a high level of security. They designed a modified integer arithmetic code that had the potential of compression and encryption all together without compromising on the coding efficiency. They stated they their future endeavors include study about the key scheduler to further improve the security.

In recent years, the splendid and swift expansion of internet and multimedia technology has introduced new and immense challenges in management of massive quantity of data. The data, in its any of the form such as graphics, audio and image can be challenging. These challenges include problems like transmission bandwidth, memory, storage and processing, efficiency and speed. This has made the efficient compression essential. A fair amount of literature has been produced to compare different techniques of data compression. With the same purpose of comparison, (31) presented a comprehensive performance evaluation of an embedded zero tree wavelet (EZW) based codec performed on the basis of Huffman and arithmetic encoding techniques. They coded sub-band decomposition coefficients into multilayer bit stream which were later entropy encoded using Huffman and AC techniques. The experimental results to compare both techniques showed that the outcome of arithmetic encoded bit stream was improved regarding bit rate as compared to Huffman encoded bit stream at the same value of threshold. They further added that Wavelet based coding offers considerable enhancement in picture quality even at high compression ratios. Besides offering good compression performance, it has the property of truncating the bit stream at any point of time during encoding process and yet decoding and reconstructing a convincingly good quality image.

The three key steps in any image compression algorithm are: transformation, quantization and entropy coding. Shapiro's EZW algorithm has been implemented in MATLAB® . The quantized coefficients were supplied to both Arithmetic and Huffman entropy coders and then outcome was evaluated. It was observed that bit budget was efficiently utilized by Arithmetic coder as compared to Huffman coder.

After investigating the results, they concluded that the arithmetic coder was better at giving bits per pixel and taking more execution time in comparison to Huffman coder. They summed up that AC could be the best choice for improved coding efficiency & better performance whereas Huffman coder could be used for the sake of simplicity and ease and to decrease the execution time. Results can further be enhanced using AC if some optimal probability estimation model could be built to represent the major list produced by EZW coder.

Arithmetic coding, being a very competent and proficient entropy coding technique, has always been an extensively studied research topic. Its latest versions are in more developed form since its origin quite a few decades ago, and it has gained attention for contributing exceptionally high coding efficiency. The technique works equally well with any kind of sample space, either it is a set of arbitrary text characters or it is a set of binary files. A lot of data compression methods use AC for compression purpose after transforming the input data by some algorithm. Since a lot of researchers have worked on joint compression and encryption prospect of Arithmetic coding and have successfully developed this aspect, therefore it is believed that AC is a right choice for a possible encryption-compression technique. It can provide both security and compression for online applications.

Coding efficiency of Arithmetic coding is generally higher than other counterpart techniques. This is due to the fact that average code length of arithmetic encoded arbitrary data is the smallest. But the relatively high computational complexity is the main disadvantage of AC making it slower than other fixed or variable-length coding methods. Compression ratio attained by any encoder based on a given statistical model is in fact delimited by the quality of that model. However performance of an algorithm can be optimized in at least two aspects: Speed of the algorithm and memory requirements of the algorithm. (32) worked to shrink the execution time of Arithmetic Coding. They proposed a new multibit-power2 implementation by combining two techniques to reduce execution time of AC. Their proposed idea of implementation was the combination of two techniques; one, scale all the frequencies such that sum of all frequencies resulted in power of two, facilitating the division or multiplication by total frequency to be carried out just by simple shift operations. Other trick was the processing of more than one bit at a time to minimize the number of iterations of renormalization loop. When compared to other traditional methods, their proposed combined idea showed a noteworthy gain of about 82% in making the execution speed faster while achieving the same compression ratio. Not only they made the compression speed faster, but their proposed implementation also resulted in 38% overall gain in execution time while decompression of data.

Data compression is required for the purpose of storage, retrieval of database records and transmission of data. Various fields including medical images, remote sensing, geographical information systems, weather forecast systems, and many others require lossless data compression because if the information is lost during the compression-decompression cycle, then it renders the application useless. In recent years, Remote sensing imagery systems have become very useful instrument for government institutes, rescue teams, and for different organization to deal with infrastructure, to supervise natural resources, to evaluate climate variations, and/or to provide assistance during natural calamities. But the problem lies in the high amount of data, given that the remote sensing images data likely to be very huge; therefore high-performance lossless data compression designs are of supreme significance.

Researchers are continuously working on efficient lossless compression techniques to make them state of the art. There are various versions of data compression standards released by Consultative Committee for Space Data Systems (CCSDS) developed to shrink the quantity of data broadcasted from satellites to stations on Earth. (33) introduced a contextual arithmetic coder for the compression of on-board data. Their proposed design of entropy encoder was based on exact definition of a context model and the linked strategy to calculate probabilities using inexpensive bitwise operations for using in a fixed-length arithmetic encoder. Their contributions were integrated in a coding scheme that employed the predictor used in CCSDS-123. A near-lossless quantizer was also set up. The scanning order of entropy coder was line-by-line and bitplane-by-bitplane. Consequently, the encoder consumed only few computational resources, creating a perfect encoder for on-board data compression. Their coding scheme was based on three stages; the prediction and mapping on CCSDS-123, a possible quantization step to get lossless or near-lossless compression and then ultimately their proposed contextual arithmetic encoding stage. The experiments conducted by them indicated that the using only a single neighbor to get the contextual arrangement was fairly sufficient for suitably exploiting the contextual information in the arithmetic encoder. They also stated that bitwise operations were good enough to estimate the probability without compromising the coding efficiency. Furthermore, their results indicated that, their designed scheme improved the current standard version of CCSDS-123 for lossless coding by more than 0.1 bps on average. Comparing their model with M-CALIC, their proposed model showed an average enhancement of 0.86 bps for lossless compression, while for near-lossless, the improvement ranged from 0.13 to 0.31 bps. Their scheme accomplished the coding efficiency for lossless and near lossless compression, better than CCSDS-123, M-CALIC, and JPEG-LS. Their proposed contextual arithmetic encoder had three advantages over other modes, 1) utilizating low-cost operations to calculate the probabilities; 2) excluding the renormalization procedure; and 3) and employing a simple contextual model.

Adaptive Arithmetic Coding (AAC) has edge over Static Arithmetic Coding (SAC). In SAC, there are additional tasks of recording the probability distribution of the input data, initializing the probability range [L, H] to [0, 1] and adjusting the range iteratively according to the input data. On the other hand, in AAC there is no need to code the probability distribution of the input data in advance because it makes use of a frequency table.

Researchers have worked to enhance the performance of AAC by considering the contextual aspect of modeling. In Context based Adaptive Arithmetic Coding different frequency tables are used for different values of context C. CAAC has been broadly used for lossy, nearly lossless, and lossless data and image compression. (34) proposed five new schemes to further enhance the quality of CAAC, that includes (a) initialization of the frequency table, (b) the range-adjustment scheme, (c) the increasingly adjusting step, (d) the mutual learning scheme, and (e) the local frequency table. These techniques ended up in the convergence of frequency table to the true probability distribution in an exceptionally short period of time. The proposed idea of rang adjustment of values in frequency table was able to adjust the entries of neighboring values of the current input value altogether instead of altering just one entry of the frequency table. Idea of mutual-learning helped in tuning the contexts of highly correlated entries in the frequency table. The proposed scheme of adaptive initialization assisted in selecting a suitable model for initializing the frequency table. Local information was also used for generating a local frequency table. They performed a variety of simulations on edge-directed prediction (EDP) based lossless image compression, coefficient encoding in JPEG, bit plane coding in JPEG 2000, and motion vector residue coding in video compression. All the carried out simulations validated that the proposed techniques could lessen the bit rate and was favorable for data compression. They stated that their version of AAC has the capacity to enhance the coding efficiency of any kind of data, including images, videos, texts, acoustic signals, and biomedical signals. They also recommended future endeavors, in particular, the range-adjusting scheme. They pointed out that the research on correlation among the probabilities matching to different data values has more potential in it, and about the mutual-learning scheme, the similarity among the probability distributions of different contexts is another research direction to consider.

MAJOR OUTCOMES ARE AS FOLLOWS:

1. A JPEG2000 Arithmetic Coder using Optimized Renormalization Procedure was designed. The proposed design was an efficient and competent algorithm for the renormalization procedure, enabling the whole arithmetic coder to execute in succession, that is how shrinking the computation complexity and making the implementation on hardware easy.
2. A new design to fine tune the sizes of intervals linked with the selected symbols determined by a secret key was proposed. The design was proved to offer high level of security without compromising on coding efficiency. The proposed design also offered a modified integer arithmetic code which owned the potential of compression and encryption all together without having any affect on the coding efficiency.

3. A comprehensive performance evaluation of an embedded zero tree wavelet (EZW) based codec performed on the basis of Huffman and arithmetic encoding techniques was presented.
4. A new multibit-power2 implementation of Arithmetic Coding by combining two techniques to reduce execution time of arithmetic coding was proposed.
5. A contextual arithmetic coder for the compression of on-board data was introduced. The proposed arithmetic coder was designed to use the connecting adjacent neighbors to build the context and then to use bitwise operations to calculate the related probabilities.

APPLICATION OF ARITHMETIC CODING

Many researchers put forward their contributions, and came up with improvements and enhancements on the said topic. AC has always been a subject of great interest, a huge amount of work can be found in the literature where this technique was used in combination with other methods to achieve high performance. Image compression keeps a central position in the vicinity of image storage and transmission. For instance, image compression has been playing a key role towards the growth of multimedia computing technology. Moreover, it is the innate technology for managing the enhanced spatial resolutions of ultra-modern imaging sensors and growing broadcasting television standards. Digital images file sizes is the major problem because of the high cost these files incur while transferring data over a network. Larger image file sizes result in larger webpage file sizes, larger webpage file sizes take more time to load. Consequently user has to pay higher data transfer costs when opening these larger web pages. Images make up a considerable portion of webpage content and the image file sizes affect the page load times and bandwidth utilization of the web pages. Compression usually reduces the size of files to improve storage and online transmission of the files. Some types of files will compress better than other types, for example certain text files and BMP image files may even be compressed by up to 90%.

In this section of the paper, different application areas are summarized in which different researchers have put forward their work. Sections are differentiated based on the nature of the work

COMPRESSION OF IMAGES AND VIDEOS

(35) experimented with AC and applied this technique to sketch based Laplacian Pyramid Coding (LPC). He attempted to justify the application of AC to LPC followed by examples of compressing the image "Lena". He showed that how AC can be harnessed to context sensitive LPC. He pointed out that although Huffman coding is an optimal form of instantaneous code, but it is not efficient for LPC. He gave arguments by saying that “Huffman coding requires at least 1 bit per pixel on each level of the pyramid, thus forcing the net bit-rate to at least 1.33 bit/pixel irrespective

of the contextual knowledge." He further explained that an alternative method could be to use Elias' run-length code, but it would also be difficult to combine it with context sensitivity because the contexts in LPC change irregularly and quickly. A third possibility in his opinion was to use Huffman coding with extensions, in the form of block coding. This option was better than other two as the bit-rate was inclined towards the entropy but it was impractical and difficult to design because of the context sensitivity aspect of LPC. On the other hand, in his view, an Arithmetic Coder would perform better and be easier to design, thus allowing the designer to concentrate on the statistical model. Results from his experiments confirmed high efficiency with Binary Arithmetic Coding. The conclusion he drew from this argument was that AC is the best source coding technique as a tool in context sensitive sketch based Laplacian Pyramid Coding, allowing full focus on the statistical model.

Lossless image compression has exclusive challenges related to it. Lossless image compression works on the idea of finding and encoding the image structure of the data as much as possible, followed by the efficient encoding of the unstructured, noisy residual data. Different methods of lossless compression are of crucial importance for shrinking the irresistible storage requirements for those images where no loss of the data can be endured. The lossless compression of HDTV images has been a topic of great interest aiming the manufacturing of a system that can be put into practice with ease and affordability, the system that can accomplish fully reversible compression to a reasonable extent. The major setback when dealing with HDTV images is the involvement of high data rate, and because of this reason, the objective of effortless implementation requires saving memory space and computation timing as well. To cut down memory requirements, a method is considered suitable that doesn't need pixels from preceding frames or fields, but in one study (36), it was tried to reduce the computational time to achieve lossless coding. They didn't use a customary quantizer in his design, subsequently reducing the system complexity and eliminating the feedback loop in the encoder. In the study, author investigated the methods for the compression of HDTV image sequences. His proposed scheme was lossless in its nature. He presented a combined novel system of median adaptive prediction and arithmetic coding. Median adaptive prediction is well known and proven for reducing the complexity of the predictor and increasing the degree of compression as well. It was established in his study that an arithmetic coder can achieve the rate of encoding a signal close to its entropy. Rate of compression of test HDTV image sequences was approximately one-half of their original rates. He got excellent results by his novel combined model of median adaptive intra-frame prediction and arithmetic coding. Compression rate of interlaced HDTV images was approximately 55% of their original rate. Image storage and full-quality data exchange are aimed applications of this study.

Continuing with the topic of lossless compression, (37), in one of their study, identified the three vital components necessary for a good quality predictive lossless image compression method, these are; image modeling and prediction, error modeling, and error coding. They explained the method as three steps: first predict the value of every single pixel, build a model for error of the prediction, and then encode the error of the prediction. The prediction values correspond to lossy compression; on the other hand, encoding the error of the prediction makes it lossless. Their method with three different steps evidently separated the tasks of image modeling, error modeling, and error encoding. They gave a scheme for error encoding based on arithmetic coding comparatively more functional and practical when employed to a set of Laplace distributions. Arithmetic coding was used to encode errors, believing that the errors were distributed over Laplace distribution. Compression was completely lossless utilizing a reasonable amount of memory. The compression ratio was superior to that attained by contemporary lossless image encoding techniques.

Lossless and lossy data compression techniques both have their pros and cons depending on the situation in which the techniques are used. Lossless gray scale or colored image compression becomes indispensable for various reasons, for instance medical imaging etc, while lossy image compression is imperative in several other scenarios as well, due to ability to achieve high compression ratio. (38) proposed a lossless image compression technique by means of a lossy image generated with JPEG-DCT method to take advantage from both types. They presented a successful lossless compression method for gray images that used lossy compressed images. JPEG-DCT algorithm was used in the lossy compression scheme. Their concept was to use a JPEG-compressed lossy image primarily, then use the residual information for the reconstruction of the original image by means of both the lossy image and residual information. They used AC at entropy coding stage. It was made adaptive in a way that the pixels of the different edge levels were encoded autonomously. That is how the statistical parameters of distribution of source symbol were utilized wholly by using the method of 3-dimensional adaptive prediction and adaptive arithmetic coding.

(39) presented their work focused on exploring more efficient and competent methods of achieving lossless compression; i.e., the process of compressing images without losing the quality of the images. Their proposed method was based on two stages. In the first stage the unprocessed image data was de-correlated by using a two-dimensional, causal linear predictor that resulted in a noteworthy reduction in entropy. In the second stage, standard coding methods were used. Comparison was done among different two-stage schemes with respect to their performances on various images, using bi-level coding, arithmetic coding, and adaptive Huffman coding. The purpose of using entropy encoders was to take advantage of the amplitude probability distribution of raw data, and subsequently, entropy encoders provided best possible data compression. The compression performance of three encoders was compared at the second stage, using three distinct images from the University of Southern California Signal and Image Processing Institute's image

database. It was observed from the experiments that the two-stage compression scheme involving an arithmetic coder performed better than all other contemporary techniques in all cases.

Lossless encoding of images and image sequences has always been one of the key and central tasks for multimedia applications that are heavily reliant on the performance of competent and proficient coding techniques. Preferred quality of compressed data, compression ratio and the image resolution may vary for different applications and for different users. Therefore, coding methods that can re- construct the compressed images by using predefined subsets of the bit stream remained in the limelight recently. (40) argued about the practical use of conditional arithmetic coding in a Laplacian pyramid in one of their study. Their proposed technique was, in its main characteristics, analogous to the conventional pyramid approach. They preserved the basic idea of using Laplacian pyramid type decomposition; but the bit allocation method and quantization method, and the way they utilized filters for pyramid decomposition was novel in their proposed idea. The pyramid was first quantized and then encoded followed by a layered quantization approach along with a layered coding method based on conditional AC. They used simulations to show that the conditional arithmetic coder performed better than the pyramid zero-tree encoder even when used with a simple model for the context.

(41) presented a novel technique for encoding the labeled images that are frequently used to identify location of the object in region-based image and video encoders. They stated that two schemes were classically used to encode this kind of images: 1) a contour-based scheme and 2) a label-based scheme. They compared their proposed method with an arithmetic encoder used in MPEG-4. The experimental results showed that the contour-based method had considerably lesser encoding cost than the Q-coder in most of the cases. Their suggested contour-based scheme outperformed the AC based on the probabilistic model used in MPEG-4. Moreover, their scheme was broader and general than the Q-coder and could be used for any labeled image. Overall, their proposed idea seemed to be a potential candidate for the compression of labeled images in the framework of region-based coding. They believed that the encoding of the chain codes could be further enhanced. Their future interests included definition of other patterns with several states, and the optimization of statistical encoding method of the chain codes.

The scheme of finding control points, i.e., points that are essential for the reconstruction of the image, proposed by P. J. Toivanen in 1993 and 1998, had a problem related to it. The problem of using control points in gray- level image compression can be divided in two sub- problems: 1. How to find optimal locations for the points, 2. How to compress the points containing both a spatial coordinate and a gray value. He used Huffman coding for the compression of control points in his previous studies. To cope with the above mentioned problems (42) suggested a new sliding window AC method and proved that the new method was superior to Huffman coding in control- point based image compression. The stepwise method was described as: (a) First, the image was scanned following Hilbert curve yielding one-dimensional stream, (b) This stream was converted into two new streams, (c) The first stream contained zeros and ones, 'zero' indicating no control point and 'one' indicating control point, respectively, (d) The second stream contained the values of control points. The second stream was supposed to be significantly shorter than the first one since there was very little number of control points in the image. Both streams were compressed separately using AC with sliding window. The authors used this method for the compression of gray-level images, where both the positions and gray-values of the points had to be coded. The compression ratio of their proposed idea was 50-200% better than the Huffman's technique used previously by Toivanen in 1998.

The topical expansion of multimedia data has established the use of images and audio/video data in a variety of applications as web, image database, telemedicine, and so on. Worldwide standardization organizations are putting in their efforts to standardize the compression techniques of image signals. The main aim is to reduce the communication bandwidths and minimize the storage space and at the same time maintaining the visual quality of the original image. GIF (Graphics Interchange Format) from CompuServe Inc is one of the most accepted forms of indexed images. The GIF images are usually used for transmitting the artificially created computer game units or online computer graphics instead of real images. Studies have shown that re-indexing of indexed images is possible without any loss of data provided that the color palette can support it; believing that if a suitable re-indexing method is selected then a better compression ratio can be realized. (43) proposed a new method for the efficient compression of indexed color images using AC. Their algorithm could achieve lossless compression on palette of 256 colors images without even converting them to grayscale images. It worked by finding the co-occurrence value of every index value, transforming to ranked images and compressing the image data and then reconstructing them. The arithmetic coder accommodates to the local characteristics of an image by dividing each range according to the frequencies of each color index. A 256-color image has indices between 0 and 255.

Authors used the co-occurrence matrix of size 256x256 to rank the frequency of color's index of neighbor of every color index. A higher rank shows higher co-occurrence rate, and vice versa. Consequently, coding redundancy can be maximized by gathering ranks data. This method improved the performance of entropy coding at the subsequent level i.e., Arithmetic Coding. AC was chosen for the task because it showed a compression ratio better than Huffman Coding or LZW algorithm with target symbols having skewed distributions or small variance. Compression ratio could be further enhanced up to 10 - 15% if characteristics of the image are adjusted on the whole.

With the advent and growing applications of multimedia technologies such as videoconferencing, internet and database systems, higher performance of image compression has become a necessity. Compression of images is vital for reducing the storage space, the transmission time and for saving the communication bandwidth. Performance of image compression systems can be measured by quality of the compressed image and the attained compression ratio. Although literature gives us plenty of research pursued for various proficient image compression techniques with effective features developed to deal with the needs of multimedia and internet applications, but still more research ideas are floating everyday on this topic. We know that lossless image compression reconstructs an image identical to original image but compromises on compression ratio, whereas lossy compression techniques cannot reproduce original image after decoding but can give better compression ratio with high quality reconstructed image. Due to the high correlation among the neighboring pixels of an image, high inter-pixel redundancy is present in images, where neighboring pixels having more or less the same value. Lossy compression techniques used this redundancy to attain high compression ratio. (44) proposed a competent lossless image compression technique based on easy and straightforward arithmetic operations. They used repeat reduction and AC to enhance the outcome of data compression. Repeat reduction was used prior to the encoding process followed by AC because of its ability to represent a pixel with fractional number of bits. The results achieved were good for different images particularly for face images. Their suggested method showed better outcome for more redundant data but it showed slight improvements for less redundant data in comparison to the results of the existing methods. They also investigated the complexity of their method regarding compression ratio. The proposed scheme is most applicable for those images where lossy compression is not desirable.

Joint Video Compression and Encryption (JVCE) became popular and acquired importance few years ago to cut down the computational complexity of video compression, and to offer encryption of multimedia content for web services as well. JVCE schemes provide encryption at low expenses without altering the formation of multimedia content. (45) presented a JVCE framework based on Binary Arithmetic Coding (BAC) and proposed security improvements to make the method more secure against cryptanalysis. They described an interpretation of BAC as a chaotic iteration on skewed binary map. They proposed a more robust Chaotic Binary Arithmetic Coder (CBAC) scheme using this model, that incurred no computational or memory cost, the method provided additional possibilities of interval ordering. They describe seven other potential chaotic maps that can give comparable Shannon optimal performance as BAC. The modification of BAC proposed by them preserved the overall length allotted to each symbol within the range [0,1), but the selection of map required to encode every symbol was reliant on the key. The CBAC had the functionality to scramble the intervals without altering the width of interval in which the codeword has to lie, thus allowing the encryption without compromising the coding efficiency. They also proposed a security improvement to counteract the identified attacks against AC based techniques.

In video encoding systems, while compressing texture information using adaptive AC, the symbol probability model have to be re-trained every time the coding procedure shift into the area having varied texture. H.264/AVC is high-tech and up-to-date video encoding technology configured to use Context-based Adaptive Binary Arithmetic Coding (CABAC) for the encoding of texture and motion information in applications where maximum compression performance is desired. (46) enhanced the competence of CABAC technique by establishing the idea of region-adaptive probability model selection. This enhancement was not simply valid for CABAC in H.264/AVC but it could be tailored for any video or image encoder, present or future, using adaptive probability models. They retained raster scanning order of the encoding process. Various switchable sets of probability models were used instead of original set of probability model to encode texture information. Every frame was divided into square tiles, and each tile was then associated with one of the on hand sets of probability models. Inside a tile, just the active set of models was trained and adapted; rest of the sets remained untouched, all geared up to be activated in several other regions. Their model was able to minimize the effect of probability miscalculation while shifting among different regions of image with different texture characteristics, without any significant increase in computational complexity. Bit rate savings of 0.75 to 1.6 % for CIF sequences and 3.5 to 4.5 % for 720p resolution sequences were obtained.

When Lossless Data Compression is crucial and essential, owing to the need of every data to be preserved, it is therefore a necessity to make noteworthy breakthrough in the compression performance. (47) proposed a straightforward lossless scheme to compress all sorts of images with the comparable high rate of compression. The method worked in two steps; (a) get the residual of data by removing the correlation among pixels using Snake Scan, (b) encode the residual of data using AAC. They named it Adjacent Data Probability on Adaptive Arithmetic Coding (ADAAC). Probability model was developed by simply using adjacent data. Compression rate of the suggested scheme was tested on 24 color images presented by Kodak Company. The compression performance of proposed algorithm was superior to AC and AAC algorithm, and it could further be enhanced by making use of the relativity between adjacent pixels for coding. After experimental outcome of six groups, it was established that the compression performance of RBG combining was better than RBG dividing.

The modern lossless image compression techniques consist of two distinct and independent phases: (a) statistical modeling and (b) Encoding. Credit goes to these two separate phases that the AC offer noticeably better compression performance than other techniques, therefore it has been extensively used by the majority of image and video standards, for instance JBIG2, JPEG2000 and H.264/AVC, and by multiple lossless data compression schemes operating on bit, pixel, or predictive error pixel-level. (48) worked on finite mixture models (FMM) and adaptive arithmetic coding (AAC) for block-based lossless image compression and proposed an efficient AAC for lossless image compression based on FMM. They proposed the modeling of each block using appropriate FMM by maximizing the probability of samples of that block. The parameters of mixture models were projected by using maximum likelihood with Expectation-Maximization (EM) algorithm to maximize the efficiency of AC technique. The performance of the mixture models for lossless image compression was proved by studying the comparison of some particular test images. They observed considerable enhancements over classic adaptive arithmetic encoders and the modern up-to-date lossless image compression standards. Their experimental results demonstrated that the compression efficiency of the suggested method gave better performance than conventional arithmetic encoders and the most recent lossless image compression standard, JPEG-LS, by more than 21% and 31%, respectively.

PCA has been used jointly with various redundancy removal algorithms, e.g., JPEG2000 and discrete wavelet transform (DWT) for compression purposes. (49) proposed a scalable compression algorithm for face images supported by Principal Component Analysis (PCA) and Entropy Coding. Their idea was to use PCA and a number of patterns from training face images, out of which the most representative Eigen image could be extracted. Encoding of the human face images was done using merely the first term of the extracted eigen-images to minimize the coding complexity and maximize the compression ratio at the same time, i.e., only the eigen-image with maximal energy strength was chosen for the encoding process. In their experiments, PCA was applied to extract the most representative part of the face images that are intended to be compressed, and then ultimately AC was applied as the entropy coder to produce the final bit stream. Using the arithmetic coder reduced the number of bits for representing the original eigen-image. They justified the use of PCA with AC by experiments and showed that the suggested algorithm can achieve a good tradeoff among the computation complexity, compression ratio, and image quality.

Compression of Medical Data

Importance of lossless image compression amplifies when images are acquired at greater cost and are intended for advanced processing. Therefore, medical images, image archival systems, and remotely sensed images are all true contenders of lossless image compression. Compression of medical images has been of great interest because of the huge volume and size, many endeavors has been made in this regards to facilitate their storage and transmission bandwidth requirements. Conventional transform-based methods used for image compression, although effective, are lossy. In case of biomedical image analysis, even a minor compression loss is unbearable.

Thus lossless techniques are always preferred. In case of medical images, two things to keep in mind are: some distortion has to be tolerated in the recreated images to get better compression ratio; while keeping the distortion low to guarantee utmost diagnostic quality.

ECG data compression posses a central position in many applications because of the storage requirements, fast transmission and analysis of signal information. (50), a hybrid scheme for the compression of data was adopted, using AC technique with renowned customary adaptive sampling techniques such as Turning Point (TP) and FAN (Sapa-2). They suggested a novel approach that could be more practical in case of real-time operations. They put stress that AC can improve compression rates of the signals if used in ECG data compression. AC is easier to implement in real-time microprocessor- based instruments owing to the computational efficiency of the algorithm. Their algorithm was evaluated by performing clinical experiments using two groups of specialists; achieving a 99% diagnostic sensitivity proved that some distortion brought in by the ECG data compression scheme could be regarded as clinically insignificant.

(51) proposed an improved DPCM (differential pulse code modulation) based system for lossless compression of medical images. The process was to generate a residual image (prediction error) at the transmitting end by performing the subtraction operation between the predicted value and the current pixel intensity value. Original image was reconstructed at the receiving end by performing the addition operation between the predicted value and its error. Assuming that the distribution is Laplacian, prediction errors can simply be encoded using the Q-coder as a mixed-context binary source for generation of strings having bit rate lesser than the first-order entropy. Therefore Q-coder was employed to encode the residual image data. Since the Q-coder is an adaptive arithmetic coder, it can adapt to different images without re-designing its codebook; therefore, it is a high-order entropy coder. Consequently, they observed that encoding of errors of 4- pixel linear/non-linear prediction using Q-coder offered the bit rate equivalent to 2.74 bpp less than the bit rate of first-order entropy of the prediction errors, 2.76 bpp. They investigated three prediction ideas namely optimal linear prediction, non-linear prediction using multi-layer perceptrons, and hierarchical prediction.

(52) focused on the lossy methods with slight distortion, or near-lossless image compression methods. They investigated the near-lossless scheme for the compression of medical images. By "near-lossless", means lossy but high-fidelity compression using the entropy-coded DPCM technique. Their method was novel in a way that it used a context- based source model and the AC technique to compress the quantized prediction errors. Their new idea could considerably improve the performance of the DPCM technique. Source modeling based on context helped to decrease the entropy of certain data sequence by means of using the contexts or

conditional events. They evaluated their model with respect to compression performance and the quality of recreated images. They used various Magnetic Resonance (MR) and Ultrasound (US) images. Experiments showed that the DPCM method using entropy encoding can enhance the compression ranging from 4 to 10 with a maximum SNR value of about 50 dB for 8-bit medical images. Exploiting multiple contexts also enhanced the compression ratio by 25% to 30% for MR images and 30% to 35% for US images. Comparative evaluation with the JPEG standard revealed that the entropy-coded DPCM approach offered about 7 to 8 dB improvement in quality for the equivalent compression performance.

Medical imaging systems use high quality images and are linked to databases for managing and advanced processing. Traditional digital medical x-ray images need large amount of memory and high bandwidth for storage and transmission purposes, respectively. Therefore, the digital medical images must and should be compressed or encoded lossless prior to storage and/or digital transmission. A very eye-catching technique for the compression of medical images is the wavelet image compression that uses the Set Partitioning In Hierarchal Tree (SPIHT) proposed by Said and Pearlman in 1996. This technique has the ability of progressive transmission and it may also support ROI interest lossless compression. The SPIHT is a straightforward algorithm that receives gains from the spatial orientation of the zero trees proposed by Shapiro in 1993 and has been revealed to offer enhanced performance. (53) presented an enhanced lossless image compression technique called partial SPIRT based on SPIHT. In their novel approach, they used threshold limits depending on the frequency of 1s in each bit plane. The technique was designed to use the traditional SPHIT in each bit plane provided that the frequency of 1s is less than 0.2; if not, then SPIHT was not applied for that certain bit plane and two other new alternatives were exploited instead. The suggested algorithm offered better lossless compression performance than SPHIT, because the efficiency of SPHIT dropped down when it transmits the lower bit planes. They also used arithmetic coder based on bit plane in which they reset the frequency table and the cumulative frequency table to the preliminary values in each bit plane. Their suggested partial SPIHT was evaluated against the standard SPIHT. The results showed better compression performance than SPIHT for most of the test images. SPIHT had higher compression for the mammogram image having a large background area that contained a huge amount of 0s. The threshold limit values were calculated by experiments values and were strongly matched to the theoretical values.

In radiology, image storage and transmission is critical area, therefore lossless techniques are frequently used for image compression. Lossless compression is believed to be the only way of image compression accepted by the doctors and physicians. The inclination towards the lossless compression is because of the verity that these techniques maintain the integrity and reliability of the medical data let alone the diagnostic faults and errors. Yet, lossless compression techniques cannot considerably shrink the volume of images data.

Mainstream lossy techniques can reduce the volume by compressing the images provided that the compression losses will not reduce the quality of images so that the physicians can confidently make use of these images for diagnostic purposes without any errors. (54) presented a study of the IRM images lossy compression based on the discrete cosine transform DCT allied with AC technique with an aim to reduce the size of the image maintaining the quality of the reconstructed image simultaneously. The coefficients were encoded using AC. This lossy compression/ decompression technique was tested by means of two IRM images of the brain, from two different view, i.e., axial and sagital, of a patient who was suffering from cerebral hemorrhage. The results they obtained from those images showed that the DCT method allowed to significantly enhancing the compression ratio whilst maintaining the quality of image with varying threshold within the interval: 0 TH 20 for block sizes: [16x16] and [32x32]. However, on the threshold value greater than 30, a rigorous deprivation in the quality of the reconstructed medical image was experienced.

Image Compression is not only crucial in terms of well-organized storage, competent manipulation, and fast transmission, but in medical systems the aspiration to safeguard the diagnostic validity of the image is vital as well. Therefore it is necessary to use the lossless compression techniques. The major challenge encountered by the medical image compressors is to preserve the quality of diagnostic image while attaining the high compression efficiency. (55) proposed a novel near-lossless context based compression technique. It was an outstanding idea offering superior performance in terms of high visual quality of the recreated image and comparable computational efficiency. Using the contextual information allowed chosen areas of the image (contextual region) to be encoded with superior quality as compared to the less important areas such as background (patient information and image parameters). In the suggested technique, base points, direction images and D-value images were acquired from RGB color space image by transformation. Base points and the direction images were encoded by distributed arithmetic coding, while Huffman coding was used to encode the wavelet coefficients of D-value images. Consequently, high compression rates, improved diagnostic image quality and enhanced performance were achieved on the whole. Tests were conducted on experimental medical images from various modalities and different body parts and results are reported.

Medical imaging is one of the hot research topics that have gained much attention because it necessitates speedy and proficient image compression to maintain the clinical work flow and to save the costs. Multi-dimensional high-resolution medical imaging devices like computed tomography (CT) or magnetic resonance imaging (MRI) scanners produce hundreds of high resolution images every year. Huge raw datasets generated by these devices require high storage space and incur high transmission costs in hospitals, so it is highly desirable to compress the data. Precise diagnostic conclusions call for the need of lossless compression. And besides that, effective clinical work flow demands a speedy and efficient encoding/decoding algorithm, e.g., the transmission of data among workstations. Reconstruction, visualization, and other complex computations involving various image processing tasks are performed by graphics processing units (GPUs) deployed at workstations. These units are powerful but inexpensive consumer graphics processing units (GPUs). GPUs are intended for extremely parallel arithmetic computations, so it is quite practical to utilize their computational power for better encoding of images. (56) proposed an image encoding system for Nvidia's GPU programming language CUDA that consisted of a pixel-wise prediction stage followed by an arithmetic entropy encoding stage for the prediction error. They offered an extraordinary parallel lossless medical image encoder that could achieve lower data rates comparative to other image and video encoders. They used block-parallel least-squares prediction followed by BAC. They stated that advantage of working with a GPU implementation was that the CPU was still totally accessible for various other tasks, giving benefit to the user to straight away carry on working during compression and storage of huge volumes of high resolution medical images. Those were the efficient features of their technique making it appropriate to implement it in practical systems to support smooth clinical work flow and to lessen the storage and transmission costs in hospitals. They emphasized the importance of using GPUs, as in the coming years, GPU cores will increase in number and as a result the speed of their presented method will keep on rising, guaranteeing the applicability of the suggested idea for rapidly increasing image resolutions. Comparative results of proposed method and contemporary image and video encoders showed efficiency gains of 3.3–13.6% while reducing the compression times to a few seconds.

Compression of Data for Transmission

One of the major issues in the field of Information Technology is the reliable and secure transmission of data. Transmission of data over media should be made secure enough so that it becomes less vulnerable to any loss and tampering by external forces. Compactness of data sent over a medium adds to its performance and supports safe and protected transmission as well. In practical scenarios, compactness can be accomplished through data compression that helps to significantly reduce the required storage space and to considerably increase the transmission capacity of the media. Compactness of data is termed as "bit-rate reduction" that focuses to minimize the number of bits representing the secret information therefore maximizing the capacity of transmission media on the whole.

(57) reported an AC data compression codec for transmission of newspapers in his study. This codec was put in use in May 1992 in national transmission network of CHINA. He stated that Chinese words and raster photograph newspaper page of

resolution 24Pels/mm have been compressed about 10 by using a limited accuracy algorithm, contrast to the Huffman code, by which compression ratio was only about 5. He made a conclusion that the arithmetic encoding techniques for data compression can be put in use in real-time using appropriate hardware.

When the information redundancy is reduced, it becomes more prone to errors, therefore error detection and error correction methods must be applied to lessen the transmission error. Block Cyclic Redundancy Check (CRC) is a well-known and potential technique of error detection in contemporary data communication systems. Although efficient, but it has a major drawback, i.e., it can only identify errors after receiving and processing an entire block of data. Considering this disadvantage of CRC, (58) proposed a new "continuous" error detection method coupled with AC. They offered a new way to achieve balance between the amount of added redundancy and the amount of time required to sense an error once it happens, since these are two desirable but incompatible features. Their basic idea was simple, as they stated: "add, to the list of data symbols to be arithmetically encoded, an extra "forbidden" symbol that is never actually transmitted, but for which a controlled amount of probability space is reserved nonetheless." They exploited the fact that if the system decoded the forbidden symbol, then this was a guarantee that an error certainly happened. Their new error detection approach was well suited for ARQ-based communication systems and concatenated coding systems as well. The novelty suggested by them was the capacity of the method to be actually combined with the source entropy encoder in a single device (i.e., the arithmetic coder), hence giving it the ability to be more reactive than block CRC-based approaches by detecting errors in advance of the end of the block. The proposed continuous error detection scheme showed considerable gains over conventional block codes for both ARQ and forward error correction frameworks.

Ironically, the accepted view of researchers about handling the transmission of images over noisy channels is to avoid using the arithmetic coder because of its widely known error-sensitivity. (59) demonstrated that it was quite doable to overcome this weakness from an ARQ-based transmission system, and moreover it was pretty likely to exploit it for the enhancement of system's performance. Their scheme was to systematically create a perfect balance between the added redundancy and the time of error-detection, to get considerable advantage in bit rate throughput over traditional ARQ methods for all probabilities of error. They introduced an innovative method of accomplishing ARQ-based image/data transmission by the support of a new technique of error detection based on the AC. The method was an efficient approach to sense errors "continuously" in the bit-stream by inserting a controlled amount of redundancy during the arithmetic encoding operations. As we know that in AC, data strings are mapped to code strings representing the probabilities of the corresponding data strings, owing to this fact, it is straightforward to say that having a single error in an arithmetically encoded stream can be disastrous for the remaining stream. Loss of synchronization is another outcome of an error in an arithmetically encoded stream because all consequential symbols that are decoded would be useless. Authors introduced the idea of forbidden symbol. Their fundamental design was simple, and consisted of inserting, to the list of data symbols to be arithmetically encoded, an additional “forbidden” symbol, not ever transmitted in reality, but for which a reasonable amount of probability space was held in reserve however. The idea was to use that excess redundancy to detect errors: errors could be identified by the decoder when it gets itself in the “forbidden” probability zone; it senses that it is in illegal zone and the error in transmission has occurred. This novel approach of ARQ lets the retransmission of packetized data in a more competent way; by merging the source coding and channel coding into single operation. Their scheme of ARQ was not merely simple to implement than other customary ARQ approaches but it was notably less expensive with respect to the number of gates required to execute both source and channel coding. Furthermore, their new method of ARQ was more practical for image (and audio) transmission since they combined entropy encoding and error control mechanism into one operation in their new scheme, and at the same time offering appreciably enhanced quality of image at all bit-error probabilities provided a fixed end-to-end delay.

Although AC bear fruit of superior coding efficiency as compared to other entropy coding techniques, but it lags behind being not capable to localize errors. As the codewords are of predetermined fixed length, so corrupted codewrod can be discarded and subsequent symbol can be decoded without any setback. AC can’t clearly specify patent boundaries between two adjacent codewords until it decodes the bit stream. It can’t identify errors while decoding and validate all decoded symbols unless it uses termination symbols. Moreover, a huge segment of the decoded bit stream needs to be discarded upon ultimately detecting an error, because AC cannot be reversed.

In traditional packetization techniques, the entropy coder needed to be restarted at the start of every packet bit-stream that had significantly reduced the coding efficiency of the arithmetic coder. To cope with this drawback of AC (60) proposed a novel scheme to enhance the rate of error detection in AC technique. To keep the correctly decoded segments within the bit stream, they introduced segment markers in the coded bit stream without re-initializing the arithmetic coder, hence improving the quality of the reconstructed image. Their proposed technique allowed narrowing down the position of the error just to a small segment in the packet. Consequently, knowing the location of the error ensures that all the segments prior to the corrupted one would still be correctly decoded. Authors worked to improve the previous idea of resynchronization markers, because they had few deficiencies such as the resynchronization marker had to be distinctive and unique, and comparatively longer which can radically add to the bit stream length. In addition, the arithmetic coder had to be re-initialized, thus reducing the coding efficiency of the coder. To avoid above deficiencies segment markers were presented, as a replacement of resynchronization marker. Arithmetic coder was used to encode the segment markers to add them at the explicit positions in the bit stream, hence not much increasing the overall length of the bit stream. Re-initialization of the arithmetic encoder was not required as well; thus, maintaining superior coding efficiency. MPEG-4 and JPEG 2000 both have implemented segment markers for error resilient image compression. Experiments were performed using both MPEG-4 and JPEG 2000; results indicated that segment marker provided significant PSNR improvement with less than 1% increase in bit stream size.

Increase in sub-band coding of images has been observed until recently, since sub-band coding of images provide progressive transmission by producing an embedded bit stream. Progressive transmission facilitates in coping with heterogeneous network environments, and in addition it has its own remarkable importance and worth for various systems, especially network-centric computing environments such as the World Wide Web. Due to the lead that sub-band approach has over other techniques; this compression scheme has widely been accepted in image coding standards such as JPEG2000 and MPEG-4. (61) considering the importance of sub-band scheme proposed a new sub-band coding method to compress document images. Their idea had foundation on nonlinear binary sub-band decomposition followed by the concatenated AC. The suggested concatenated AC is executed supported by conditional contexts rightly chosen by utilizing the nature of the sampling-XOR sub-band filter bank and above all winning the gain of non-causal prediction potential of sub-band coding. Simulation results showed the proposed sub-band coder endowed with better compression of document images. They put emphasis that if a context set of a large size is used for the encoding of an image of finite size, then it could demean the compression efficiency, and the reason behind it is that in arithmetic coder probability distributions are usually updated during encoding of the current image and utilizing large context set for small images causes short learning of data.

If probability space of an arithmetic encoder is reserved then it can offer potential error detection and error correction while using it with a sequential decoding algorithm. With the rising recognition of arithmetic encoding technique, curiosity in the expansion of joint source channel coding schemes using arithmetic coding has also been increased. (62) proposed a scheme that combined the compression by AC with a finely adaptable capability of error correction to offer an influential joint source channel encoding approach. They presented a Trellis Coded Modulation scheme to present a suitable tree for a list decoding algorithm. Experiments were conducted on both a small alphabet application (SPIHT encoded image) and a large alphabet application (predictive lossless image compression). Simulations on AWGN channels with bit error rates in the range of lop3 to 10-1.5 showed noteworthy packet recovery rates even for the poorest channel.

Arithmetic coding has already been broadly used in mesh compression, but it is extremely receptive to bit errors. An error bit can affect the interval test at some point, resulting the decoding of incorrect symbol. Consequently all upcoming symbols would be decoded incorrectly as the arithmetic encoder will lose synchronization. Even if AC is not used, the coefficient of bit modeling that produces coded symbols is sensitive to errors as well and can go out of order following a single bit error. Just one bit error can destroy all the subsequent coded data. For example, half of the model will be lost if the error arises in the center of the bit stream. Yet another and worse situation would be that if the error is not sensed at all, random data would be decoded and a model having no similarity with the original one would be the outcome of decoding. Another scenario is of the misplaced packets, the affect would be the same, i.e., decoding of an erroneous bit stream. Error detection is accomplished via checks inserted in the residual redundancy on the coded data and inclusion of segment markers.

(63) studied an error resilient 3D mesh coding algorithm that employed an extended multiple quantization (EMQ) arithmetic coder method. 3D streaming has already been an area of interest for being successfully representing 3D models in a compressed form and effectively broadcasting them on the limited-bandwidth and lossy channels. They got motivation for their study from the error-resilient JPEG 2000 image encoding standards. Their idea was that the error resilient EMQ coder divided the bit stream into small independent components and enabled the fundamental transmission error containment, using periodic arithmetic coder and termination markers. The encoder used a shape adaptive mesh segmentation design to lessen the effect of error transmission. An input mesh surface was roughly divided into components, and every component was additionally compressed by the EMQ coder with periodic arithmetic and terminating markers to facilitate the transmission error containment. Their designed EMQ coder had also the inherent aptitude of managing noise by using the maximum a posteriori (MAP) decoder. Experimental results showed that the proposed method has improved the mesh transmission quality in a simulated network environment.

Recently, several studies on Joint Source Channel (JSC) exhibits that it is center of interest for many researchers. Several contributions made by the researchers have shown that JSC decoding is a great dominant method to correct the errors when transmitting the entropy encoded streams. (64) presented a novel method for JSC decoding of Arithmetic Codes supported by Maximum A Posteriori (MAP) sequence estimation. The suggested method performed Chase-like decoding by utilizing prior knowledge of the source symbol sequence and the length of compressed bit stream. Their method could be regarded as a joint source/ channel decoding scheme and showed plentiful noteworthy benefits. The reason behind good error correction performance was Chase-like arithmetic decoding particularly for medium to high SNR values with no need of added redundancy in the compressed bit stream. Another bonus their technique offered was that, contrasting from trellis-based arithmetic decoding methods, the scheme had less complexity and it was easily extendable to adaptive arithmetic codes. Their technique was evaluated with respect to PER, average PSNR, and visual image quality. Their first experiment was about lossless predictive compression, results of which showed that the Chase-like arithmetic decoder corrected the residual errors launched by the channel. These errors were actually the reason of degradation in the quality of the image. In the comparative study, they found out that with the perspective of progressive SPIHT image compression, the Chase-like arithmetic decoder demonstrated considerable improvements in the quality of decoded image as compared to conventional arithmetic decoding. The results obtained through simulations showed that the suggested decoding scheme offered noteworthy gains in performance gain with lesser complexity than standard arithmetic decoding. Besides that, Chase-like arithmetic decoder performed outstanding in terms of packet error rate and reconstructed image quality for lossless and lossy image compression methods as well. They also showed their interest to generalize the suggested method for CABAC.

(65) worked on two aspects of compactness and security of the channel and presented their study using the preeminent method arithmetic encoding for the compression of information, and using Steganography for the secure medium by hiding the compressed data into the image. The primary goal of their study was to ascertain the key solution for the transmission of data both with respect to capacity and security. They used AC to compress the plaintext to be transferred. Steganography is a way of embedding any type of secret information under a cover medium like image, audio or video. They used Least Significant Bit (LSB) replacement steganography applying which last two bits of the image pixels were replaced with two bits of compressed plaintext. This was a repetitive process, it repeats till the end of plaintext. That is how the plaintext to be transferred was more compressed and it occupied lesser space regarding storage capacity and the information was secured by embedding it into the image. The compression by their method proved to be the excellent compression method because of superior compression ratio accomplished in comparison with all other compression schemes. High compression ratio was achieved due to the conversion of entire plaintext into single floating point number instead of using conventional ASCII codes like in Huffman coding. Their work provided an inter-platform among the compression schemes especially Arithmetic Coding and the steganography procedure.

Joint compression and encryption is an area of active research for the security of multimedia content. By convention, security of multimedia is achieved through standard multimedia codec working jointly with a cryptographic algorithm, for example, the Advanced Encryption Standard (AES). (66) proposed a new multimedia security framework. The method got its roots in the nonlinear properties of the arithmetic coder to perform entropy coding and encryption simultaneously. They came up with a technique that helped to reduce the setbacks and the necessary system resources by manipulating the probability distributions of the arithmetic coder. They were aimed at proposing an encryption technique to eliminate the shortcomings of codec supported by AC, and at the same time offering reasonably enough plan of security. The proposed technique was designed such that not any added complexity was involved in it to carry out encryption, and also the size of the compressed imaged was not increased. Thus, after the un-encrypted images were exposed to the presented method, the decoded images were still progressively displayed by the decoder image, contrary to customary encryption techniques. In their suggested technique, there was no requirement of affixing any additional bits to the coded bit stream, contrasting to most of the block ciphers. Their idea was quite practical for any multimedia coder using AC. Though, the implementation of their technique as presented by them was customized to the JPEG2000 standard, but the technique was suitable for other image as well as video codec because the proposed technique did not need any extra resources and it could function in protected mode having all the functions of the genuine codec. Also, they introduced assessments and measurements for this encryption technique. The results showed that the values of PSNR, SSIM and CTSIM parameters of images encrypted by the proposed technique were almost equivalent to the corresponding values for images encrypted using AES-CTR. Their anticipated scheme was appropriate for mobile devices as no added complexity was involved at the decoder end.

DISCUSSION

Above discussion sums up the major achievements made to improve Arithmetic Coding technique. It has been developed a lot since its inception, and widely used by many researchers. It is not only a hot research area, but it is also well accepted practically by many patents and products. It is better in performance as compared to all other contemporary techniques. Especially, comparison of Arithmetic coding was made with Huffman Coding many times, and every time, every study showed that AC is better in performance than Huffman Coding. In this paper, a comprehensive survey has been made to summarize all the efforts that have been made to improve and develop this technique. This study provides a broad understanding of application of AC for students who are new to this technique.

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