Very Low Bit Rate Video Coding – A Review

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Abstract

This paper presents a review of promising techniques for very low bit-rate, below 64 kb/s video coding. Video coding at such low rates will be a crucial technique in visual services, e.g., visual information transmission and storage. A typical application is to transmit moving videophone scenes through the existing analog telephone lines or via a mobile phone. Video compression techniques have to deal with data enriched by one more component which is the temporal coordinate. Compression techniques developed for still images can be either generalized for 3D signals, or a hybrid approach can be defined based on motion compensation. The video compression techniques can be classified into the following four classes: waveform, object based, model based and fractal coding based techniques. The aim of this paper is to provide an overview of these approaches as applied to low bit rate video coding algorithms.

Keywords : SAMCOW, MP-Matching Pursuit, DSC-Distributed Source Coding, MR-Moving Region, MB-Macro Block.

1. Introduction

The importance of visual communications has increased tremendously in the last decades. By very low bit rate video, we mean a compressed data which does not exceed 64 kb/s in the bitrate of its visual portion. The uncompressed source materials [2,3]for this kind of applications typically contain about 25 k pixels in every luminance picture and a quarter of this for the chrominance. The frame rate is also typically about 30 progressive frames per second. This results in an uncompressed bit stream of up to 10 Mb/s[3]. The desired compression ratios in this case are from 150: 1 to 1000: 1. This is a very difficult task because of the relatively small size of the original pictures in the source data.

Rate scalable video compression is appealing for low bit rate applications, such as video telephony and wireless communication, where bandwidth available to an application cannot be guaranteed. The advent of the MPEG standards [23] has fueled the interest in this area due to their rich set of algorithms and tools for compression of various video formats and sizes at different data rates, for content-based manipulation, and for interactive access to audio-visual data.

A number of standards have been defined for the compression of visual information. The MPEG (Moving Picture Expert Group) standards address the compression of video signals. MPEG-1 operates at bit rates of about 1.5 Mbit/s and targets storage and transmission over communication channels as the integrated services digital network (ISDN) or the local area network (LAN). MPEG-2 operates at bit rates around 10 Mbit/s and is designed for the compression of higher resolution video signals. The recommendation H.261 (also known under the acronym px64) was proposed by the International

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Telegraph and Telephone Consultative Committee (CCITT, now known as ITU-T). Based on this standard, videoconferencing at bit rates down to 64 kbit/s has become feasible. This requires the capacity of one channel of the ISDN. In the near future, modern visual communications applications will be possible through Public Switched Telephone Networks (PSTN) or mobile networks.

Intensive research has been performed in the last decade to attain this objective [3].Variations of the recommendation H.261 for very low bit rate applications have been defined as simulation models. For these simulation models, severe blocking artifacts occur at very low data rates. H.263 [1] has emerged to a high compression standard for moving images, not exclusively focusing on very low bit rates. The improvements in H.263 compared to H.261 are mainly obtained by improvements to the motion compensation (MC) scheme.

Much ongoing research is devoted to develop differing drastically from the existing standards by higher bit rates.

1.1 High Compression Image and Video Coding Approaches

High compression image coding has triggered strong interests in recent years. In this type of coding, visible distortions of the original image are accepted in order to obtain very high compression factors. High compression image coders can be split into three distinct groups. The first group is called waveform coding and consists of transform and subband coding. The second group called second generation techniques consists of techniques attempting to describe an image in terms visually meaningful primitives (contour and texture, for example). The third group is object based coding. Fourth one is based on the fractal theory.

A waveform based coding system involves the following steps:

1. Decomposition/transform of the image,
2. Quantization of the transform Coefficients,
3. Source coding of the quantized coefficients.

The first step transforms the image into another representation, where most of the energy is compacted in a few coefficients. The quantization reduces the dynamic range of the coefficient sand the source coding (Encoding) leads to an efficient transmission At compression factors of about 30 to 40 DCT based technique used in most of the compression standards produces blocking artifacts. All the transform coders suffer from this distortion. Unfortunately, the human eye is very sensitive to such a distortion and therefore, block coders are not appropriate for low bit rate image coding. The main artifact at high compression factors (around 50) is due to the Gibbs phenomenon of linear filters and is called ringing effect [3].

In subband coding, an image is split into a set of subband images by using a group of bandpass filters followed by critical subsampling For low bit rate subband coding (higher than 50) it is of major importance to exploit the existing zero correlation across the sub bands as proposed in [4] in order to maintain a good quality.

The second group of methods is based on second generation techniques. They attempt to decompose the data into visual primitives such as contours and textures. One approach is to divide the image into directional primitives as proposed in [5]. Segmentation based coding techniques [6] extract regions from the image data which are represented by their shape and their textural content.

Wang et al. proposed a plain vector quantization [7] with an adaptive codebook. Improvement in VQ based techniques are done in [8] for low bit rare. To avoid this artifact morphological subband decompositions have been proposed [9] which lead to good quality decoded pictures at compression ratios as high as 70-80. Following similar ideas sketch based image coding is based on extracting the contours of an image, namely their geometric and intensity information, resulting in the so called sketch picture. The texture is then defined by the difference between the original and the sketch image and is coded using waveform coding techniques. An extension of this technique has been proposed by Ran et al. [10] and is based on a three component image model. This technique divides the image into the strong edge, texture and smooth components. The strong edge component is encoded separately whereas the texture and smooth components are encoded using waveform coding techniques. A solution to find the most important image features has been proposed by Mallat et al. using multiscale edges. A double layer technique based on multiscale edges and textures has then been proposed in [11].

Promising performances provided by fractal based still image compression techniques conduct to apply fractal theory to video compression issues. Different approaches have been proposed in the past fifteen years [33, 34].

The outline of this paper is as follows. Section 2 describes advances in waveform based video coding and section 3covers about model based coding algorithms. Section 4 describes object based algorithms and section 5 covers the recently developed fractal based video coding algorithms. Conclusion and future research directions are covered in section 6.

2. Waveform Based Techniques

Three dimensional subbands coding of video has been first introduced by Karlsson et al. [12], the standard subband filters are used for the spatial directions while a DCT derived filter bank is applied to the temporal dimension. The drawback of 3- D subband coding is that the temporal filtering is not performed along the direction of motion. A solution for this is the combination of the temporal SBC component with motion compensation is proposed.

2.1 Motion Estimation

Motion estimation plays an important role in motion Compensated video compression, because of its ability to exploit high temporal correlation between successive frames of an image sequence. Although many types of motion estimation algorithm have been developed, the simplicity of the block-matching technique has made it a natural choice for most video compression standards, including MPEG, H.261, and H.263.

Block Matching Algorithm: The approach adopted in block-matching algorithms is first to divide each frame into blocks, typically 16x16 pixels. A motion vector is then calculated for each block in the current frame by searching for the best matching block within a limited search area of the previous frame. Compression is achieved by using this best-matched block, indicated by the motion vector, as the predictor for the current block. Various types of the block-matching techniques are developed so far. The full search (FS) method provides the optimal solution by exhaustively evaluating all the possible candidate blocks within the search range in the reference frame. However, massive computation is required in the implementation of FS. In order to speed up the process by reduction in the number of search locations, many fast algorithms have been developed, such as three-step search (TSS) algorithm and the new three-step search (NTSS) algorithm [13].

Recent studies show that the motion-vector distribution of a real-world image sequence, within the search window, is highly centre biased. Hence, an improved version of the well-known TSS method, the improved three-step search (ITSS) algorithm [13], specifically aiming towards low bit-rate video coding is proposed. The ITSS has much better performance and faster speed than the TSS, and NTSS.

2.2 Motion Parameters and Motion Model

Conventional motion estimators estimate global motions (camera motion) based on the brightness constancy assumption. However, this is not always true as objects may vary in brightness level, depending on the illumination conditions.

Hoi Kok Cheung et.al [14], proposed a new block-based motion estimator which is capable of estimating motion accurately under varying illumination conditions. With the static sprite coding scheme, the static nature of the sprite image does not allow a coherent representation of the variability of the lighting condition in different frames. The local motion estimator in the proposed technique gives accurate motion estimation under varying illumination conditions. Experimental results proved that system also can effectively handle pixel differences caused by brightness change in the spatial and time domains during the sprite construction and frame reconstruction stages.

2.3 Wavelet Based Rate Scalable Video Coding

Wavelet based motion compensated video coders are recently developed one. These coders provide both temporal and spatial scalability. Continuous rate scalable applications can prove valuable in scenarios where the channel is unable to provide a constant bandwidth. Rather than terminating the session, a decoder can adjust the bit rate to use the limited resources, yet produce video of acceptable quality. Such decoders are particularly attractive because of their flexibility.

SAMCOW: A technique known as Scalable Adaptive Motion Compensated Wavelet (SAMCOW) compression SAMCOW is well suited for data rates less than 32 kbps. Several techniques to improve the subjective picture quality of SAMCOW are investigated in paper [15]. These include the use of B frames, half-pixel accuracy, and unrestricted motion vectors. Eduardo Asbun [15] made improvements to the SAMCOW algorithm, including the use of MPEG-type B frames, half-pixel accuracy and unrestricted motion vectors adapted to the particular scalability requirements. The performance of SAMCOW is be comparable that of H.263+.

SAMCOW uses an embedded rate scalable coding strategy to obtain continuous rate scalability. Its main features are adaptive block-based motion compensation in the spatial domain to reduce temporal redundancy and improve image quality at low data rates, and a modified zero tree wavelet image compression schemes used on the intra coded and predictive difference frames that exploits the interdependence between the color components. This codec was implemented using wavelets.

2.4 Multiple Block Pursuit Algorithm

MATCHING PURSUIT (MP), which is a frame-based algorithm, and is a promising method for low bit rate video coding [16], An MP-based codec yields a better PSNR and perceptual quality than a transform-based codec, and its decoder is simpler [17]. However, it cannot be used in applications that require real time bidirectional communications, because the encoder consumes a massive amount of computational time. An MP encoder does not obtain all the coefficients in one step, but iteratively finds the frame coefficient that has the largest absolute inner product value between a residual and all the bases. This difficulty prevents the MP algorithm achieving its best performance and its encoder is also complex one.

In MP algorithm, an atom is composed of a base and its corresponding inner product value. The most popular approach for finding an atom is that, a residual frame is divided into blocks and, at each iteration, an atom is found within the block with the highest energy. Although the performance can be improved by finding an atom from more than one block, there is still the issue of the massive number of inner products between a residual and the bases in the blocks. Jain-Liang et.al.[18] proposed a residual in a subspace, spanned by a small number of bases within a few blocks. The bases and the blocks are selected according to the content of the residual, while the coding performance and efficiency are determined by the number of bases and the number of blocks. This algorithm achieves better subjective and objective performances and requires less runtime than one-block algorithms for various sequences at low bit rates.

3. Model Based Coding Distributed Video Coding Techniques

In this type of coding the redundancy between video data collected by cameras are considered in addition to the inherent temporal and spatial redundancy within the video sequence. This consideration significantly reduces the bandwidth.

3.1 Distributed Source Coding

The fundamental ingredient of DSC is binning- a many-to-one mapping of the actual data taken from the sources to a limited number of values. Through binning, the correlation between the sources can be exploited without any communication between the sensors. For two maximally correlated pair of feature pixels from each view, the distributed scalar quantization of the pixel values is used.

In [19] developed a novel multi-terminal, model-based video coding algorithm combining distributed source coding (DSC) and computer vision techniques. The novelty of this work lies in the use of computer vision techniques to reduce inter-camera redundancy in a multicamera setting. Distributed video coding (DSC) is utilized either for the exploitation of temporal correlation in a single video stream, or for better error resilience. Another recent work [20] developed a distributed image coding technique for a multi-camera setting with several restrictive constraints: cameras are located along a horizontal line, the objects are within a certain known range from the cameras, and the image intensity field is piecewise. This paper shows [20] how general framework can be extended to the case of model-based compression. The use of a 3D model reduces the inter-sensor exchange and it suffices to transmit this information only when there is an appearance or disappearance of features. In [20] scheme relies on 3D model-based tracking algorithm that operates independently on each of the video sequences. The tracked features points are coded using a combination of distributed compression and predictive coding schemes.

3.2 Foveation Techniques

The real-time foveation techniques for low bit rate video coding is currently developed one.Foveation is a layer of HVS modeling that describes its inability to perceive an entire visual stimulus at full resolution because of the non-uniform spacing of sensor neurons. This limitation enables the removal of extraneous resolution information to obtain an increase in compression gain without sacrificing perceived quality. Video coding that incorporates foveation modeling is called foveated video coding. Foveated video coding can provide a significant increase in compression gain beyond the abilities of uniform resolution coder [21].Apart from coding gain, the computational complexity of a compression algorithm plays a vital role in determining its feasibility. Foveation requires extra processing at the encoder. Although fast foveation techniques have been explored previously [22], the need to combine foveation processing with standard-compliant video coding techniques for real-time operation, requires further research into reducing the complexity overhead. The techniques presented [22] can be implemented using the baseline modes in the video coding standards and do not require any modification, or post processing in the decoder.

4. Object Based Coding

The subjective quality of reconstructed images may be bad at low bit rate in block based video coding when comparing to the object based coding. Object-based video sequence coding has been intensely investigated in the last few years and is also supported by the new MPEG-4 standard [23]. It has an important advantage over the block-based coding: it allows manipulation of image objects without complete decoding of the stream, and then improves the coding quality and reduces the bit rate. In such a scheme, a prior segmentation map (alpha plane) [23] of the image, which segments the image into objects is known in advance. The object-based approach has been considered as a very promising alternative to the block-based approach. It alleviates the problem of annoying coding effects, such as blocking artifacts and mosquito effects compared to block-based approach at low bit rate, especially when the blocks coincide with boundaries of different objects. The object-based approach can also provide more natural representations of the scene and has another potential benefit of acquiring the depth information of semantically meaningful objects.

4.1 Dynamic Coding

In Marc Chaumont et al [24] proposed a video-object based coding scheme using dynamic coding. The principle of dynamic coding is to set on a competition different coders of on each video object. In [24], a video-object based dynamic coding scheme using four completely different coders of a 3DModel based coder, a Sprite coder, a 2D+t Wavelet coder and an H264/AVC object based coder. The work firstly comprise a global rate-distortion optimization enabling an optimal selection of a coder and its parameters for each object, and secondly the definition of a distortion metric. When comparing traditional H264/AVC (i.e full frame) and the video-object based dynamic coding scheme for bit-rate around 100Kb/s, results are better for the object approach in terms of the PSNR text metric and the visual reconstruction. At very low bit-rates, the video-object based dynamic coding scheme can perform better than H264/AVC. However, at upper bit-rate (more than 250 Kb/s for a CIF 15Hz sequence), gains obtained by using an object approach are not strong enough to compensate object overhead (shape, texture and description overhead).

4.2 Object Coding For Selective Quality Video Communication

A more efficient compressed representation is possible if selective quality can be applied to the objects that compose the scene. For example, in the video telephony application, the quality of the foreground object can be enhanced compared to the background. The background can be coded, and therefore rendered, at a lower spatial/temporal resolution or signal-to-noise ratio (SNR). Also, faces are essential for visual communication and could therefore be coded at a higher quality. In addition, object-based representation allows greater error protection for essential objects, such as faces and foreground, while transmitting video over noisy channels.

The object based video coding standard MPEG-4 provides functionalities, namely object scalability, error resilience, and coding efficiency. However, the standard itself does not indicate how to obtain these objects. Therefore, the key to utilize these functionalities in MPEG-4 lies in the ability to automatically segment the video sequence in real-time to obtain constituent objects. If multiple views of the same scene are available, then the difference in the views can be used to compute possible delineation between objects in the captured images [25,26]. Alternatively, if only one view is available, specific objects such as human faces can be located and segmented based on some form of computer modeling. In addition, researchers have had some success in using primarily motion, but also color and texture cues, to segment objects in a single view sequence [27, 28].

When two views of a scene are available, a disparity map can be computed from those views and the scene can be segmented into background and foreground objects. As opposed to traditional disparity algorithms, these algorithms compute disparity values by matching blocks [28], image features and multiscale contours. The disparity values are calculated here to segment the objects. In addition, the segmented objects should not contain any holes, even if there is little texture inside the objects. A fast algorithm is required to achieve real-time performance.

4.3 Spatiotemporal Frequency Domain Methods

Frequency or spatiotemporal-frequency domain methods have been developed to complement or overcome some difficulties of spatial-only methods. These approaches are based on the phase shift introduced to the frequency domain representation by spatial translations. They process the entire frames simultaneously, so they are inherently robust to local inaccuracies, like local occlusion, illumination changes and motion discontinuities. Wavelet domain methods [29] are able to localize motions extracted from phase information, but they suffer from inaccuracies at motion discontinuities. The spatiotemporal filtering approaches are able to successfully estimate and localize translations, but they have a high computational cost, as they require the application of many different velocity-tuned filters to the video, in order to give accurate estimates.

In order to address these limitations, a novel approach that combines the results of frequency and spatial domain processing is proposed [30].In the multiple objects independent translational and rotational motions of the video sequence is analyzed through a combination of spatial- and frequency-domain representations. A novel algorithm is presented [38] for the simultaneous extraction of all objects undergoing translation and the background via a least squares technique that takes place entirely in the Fourier domain. Spatial information is combined with the frequency domain object extraction results, to further refine them.. This combined analysis takes advantage of the strengths of both representations, by providing reliable and computationally efficient motion estimates and object segmentation. This algorithm is being a robust to local noise and occlusion, because of its global nature.

4.4 Pattern-Based Video Coding Techniques

The very low bit rate (VLBR) video compression standards, such as H.264, MPEG-4 standards are still however unable to encode moving objects within a 16x16 pixels macro block during motion estimation and compensation, resulting in all 256 residual error values being transmitted for motion compensation regardless of their mobility. VLBR video coding using patterns to represent moving regions in macro blocks has already proved its potentiality over coding standards [31]. The most important applications of these techniques are real time video conferencing, video telephony, and video on demand by mobile terminals. However, given the importance of arbitrary shape patterns for the simplified object segmentation, these techniques have significant potential for commercialization such as the possibility of patenting the arbitrary shaped patterns for the most popular and widely used video coding standard H.264.This algorithm focused on the moving regions of the MBs, through the use of a set of regular 64-pixel pattern templates, from a codebook of patterns in Fig1. If in using some similarity measure, the MR of an MB is well covered by a particular pattern, then the MB can be coded by considering only the 64 pixels of that pattern with the remaining 192 pixels being skipped as

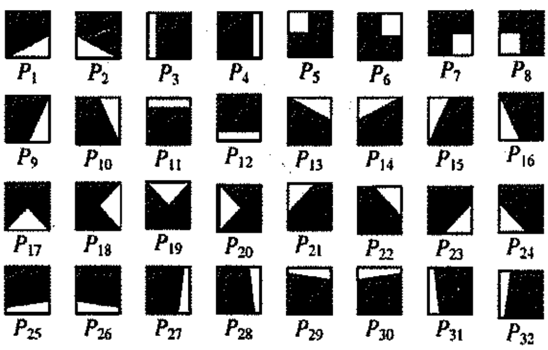

Figure 1 : PC Of 32 Regular Shaped,64 Pixel Patterns, Defined In 16x16 Blocks, Where The White Region Represents 1(Motion) And The Black Region Represents 0 (No Motion).

Successful pattern matching theoretically has a maximum compression ratio of 4:1 for any MB. The actual achievable compression ratio will be lower due to the computing overheads for handling an additional MB type, the pattern identification numbering and pattern matching errors.

In [32], a real time pattern selection (RTPS) algorithm, which uses a pattern relevance and similarity metric to achieve faster pattern selection from a large codebook, is proposed. For each applicable macro block, the relevance metric is applied to create a customized pattern codebook (CPC) from which the best pattern is selected using the similarity metric. The CPC size is adapted to facilitate real-time selection.

The RTPS algorithm [32] the size of the CPC is controlled within predefined bounds, to adapt the computational complexity of the pattern selection process, so ensuring real time operation. RTPS is able to process arbitrary-sized codebooks while this real-time constraint is upheld. Furthermore, the computational overhead of the similarity metric is reduced significantly by performing the processing on a quadrant-by-quadrant basis with the option to terminate whenever the measure exceeds a predefined threshold value. Any pattern selection algorithm using the same set of patterns for a video sequence is termed as fixed algorithm. The eight-pattern algorithm is, therefore, referred to as the Fixed-8 algorithm. Overall, the computational efficiency for the RTPS algorithm is superior to both the Fixed-8 algorithm and H.263 low bit rate video coding standard.

5. Fractal Based Coding

The introduction of a fractal coding scheme turns out advantageous especially at very low bit rates (8–64 kbit/s). The fractal coding concept originates from

Barnsley's idea to exploit self similar structures in real world images for compression purposes [33]. A first practical implementation capable of encoding grey scale images has been proposed by Jacquin [34]. Several improvements and modifications e.g. [34, 35] have been reported since then, but the basic concept of block wise approximation of the entire image by parts of itself remained the same.

According to Banach's fixed point theorem the sequence of reconstructed images converges for any arbitrary initial image to the fixed point of the transformation which is the original image. Compression is achieved if the transformation parameters can be described more compactly than the original image.

Former investigations performed by researchers indicate that fractal coding schemes are suited for applications with a demand for extremely high compression ratios. Due to the increased encoding complexity for visual loss-free coding at low compression ratios, fractal coding schemes cannot play of its advantages compared with advanced subband or transform coders. But it is more suitable for low rate video coding with applications in mobile video telephony, teleconferencing and narrow band ISDN distributed audio-visual services which rise from 4.8 to 64 kbit/s because of its high coding gain.

An efficient scheme for video coding is presented which utilizes progressive fractal coding, called wavelet based fractal approximation (WBFA) [36] and motion compensation (MC). In the scheme, the MC error frames are encoded by the progressive fractal coding. Considering the severe localization of the MC errors, irregular sampling of domain blocks in a fine step is used instead of regular sampling of domain blocks in a coarse step. It is shown that the fractal video coder presented is competitive with or superior to H.263. It also has a relatively simple structure and reveals the characteristics of non-iterative decoding, and relatively fast encoding and decoding. It is found to be more suitable for low bit rate video coding.

A novel object-based fractal monocular and stereo video compression scheme with quad tree-based motion and disparity compensation is proposed in [37]. In [37], Fractal coding is adopted and each object is encoded independently by a prior image segmentation alpha plane, which is defined as in MPEG-4. The performance results shows that it is more suitable for low bit rate coding.

6. Conclusion

The four approaches as, waveform based, model based, object based and fractal based video compression for very low bit rate video coding are discussed in this paper. The performance of these algorithms is compared as in the Table1.

The performance of these algorithms can be improved in future as follows.

(i) Adaptation of the parameters in MP Techniques such as number of blocks and number of bases, based on the input video sequence [18].

(ii) The PSNR and computation efficiency of the pattern based coding techniques can be improved by analyzing pattern similarity and relevance measurements [32].

(iii) In [31], Future directions in Spatio- temporal motion estimation and object extraction involve by analyzing the joint use of spatial and frequency data for the more complex motions, including random variations, as well as the examination and analysis of the motion of nonrigid bodies.

(iv) Very low bit rate coding mutiview dynamic coding could be developed from the existing single view coding techniques.

(v) Fractal based encoding speed may be improved by analyzing the fractal partition schemes by constraining the dissimilarity measure and the domain block search for single object

Table 1: Performance Comparison of Low Bit Rate Coding Algorithms

Technique	PSNR	Run Time of Encoder	Encoder Complexity
MP Update Algorithm (waveform based) [18]	PSNR increases with increase in L 32.63dB	205.33 sec	Complexity Increases with Increase in L(base)
Foveation model based algorithms [22]	Comparable PSNR value with H 263	Encoding time is high.	Preprocessing is required and High complexity
RTPS Algorithm (Object based) [32]	1.52dB higher than H263 (37.11dB)	200.00 sec	Less Computation complexity
Progressive Fractal Video coder (WBFA) [36]	.45 dB higher than H 263	221.25 sec	Less complexity when comparing with conventional fractal based codec

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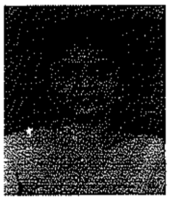

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