Chapter 1.5

Very Low Bit Rate Coding of Visual Information — A Review —

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Abstract

In this paper the compression of visual information at very low data rates is discussed. High compression coding of still pictures can be split into three categories: waveform, second generation and fractal coding techniques. Each coding approach introduces a different artifact at the target bit rates. The objective of the ongoing research is to mask these artifacts as much as possible to the human visual system. 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 3–D signals, or a hybrid approach can be defined based on motion compensation. The video compression techniques can then be classified into the following four classes: waveform, object based, model based and fractal coding techniques. The aim of this paper is to provide the readers with an overview of these approaches as well as with a list of references for further information of the details of each technique.

1.5.1 Introduction

The importance of visual communications has increased tremendously in the last decades. The progress in micro–electronics and computer technology together with the creation of networks operating with various channel capacities is the basis of an infrastructure for a new era of telecommunications. New applications are preparing a revolution in everyday's life of our modern society. Emerging applications such as videoconferencing [1], cellular videophones [2] and multimedia [2–4] will have a great impact on nowadays professional life, education and entertainment. The digital representation of the visual information in its canonic form leads to a huge amount of data. In order to meet the requirements of the new appplications, powerful image sequence compression techniques are needed to drastically reduce the global bit rate.

A number of standards have been defined for the compression of visual information. The JPEG [5] still image compressor was proposed by the Joint Photographic Expert Group and is a general–purpose image compression standard. The MPEG (Moving Picture Expert Group) standards address the compression of video signals. MPEG–1 [6] 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 [7] operates at bit rates around 10 Mbit/s and is designed for the compression of higher resolution video signals. The recommendation H.261 [8] (also known under the acronym $p \times 64$) was proposed by the International 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 for the general public. For that objective, the transmission media must switch to Public Switched Telephone Networks (PSTN) or mobile channels. The transmission of the video sequences at bit rates as low as 9.6 kbit/s will be strongly needed. Efforts of defining new standards for these applications are still in the beginning phase. Several expert groups have been created to pursue this objective. The major ones are ISO/MPEG–4 [9] and ITU–T/H.26P.

An uncompressed video sequence for very low bit rates applications typically requires a bitstream of up to 10 Mbit/s. In order to achieve very low data rates compression ratios of about 1000 : 1 are required to meet the needs of the large public. Intensive research has been performed in the last decade to attain this objective [10, 11]. Variations of the recommendation H.261 for very low bit rate applications have been defined as simulation models in COST 211ter (SIM3) [12] and in ITU–T H.26P (TMN) [13]. For these simulation models, severe blocking artifacts occur at very low data rates. Much ongoing research is devoted to develop methods based on philophies differing drastically from the existing standars developed for higher bit rates. The aim of this paper is to provide the readers with an overview of existing approaches targeting very low bitrates and with a list of major publications for further details.

The outline of this paper is as follows. Section 1.5.2 gives a review of high compression image coding techniques. Section 1.5.3 overviews video coding techniques aiming at very low bit rates. They have been classified into four classes, namely waveform, object based, model based and fractal based coding techniques. Then, pre– and post–processing of the visual information is overviewed in section 1.5.4. Existing products in the market are described in section 1.5.5. Finally, conclusions are drawn in the last section.

1.5.2 High compression image coding

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 techiques attempting to describe an image in terms visually meaningful primitives (contour and texture, for example). The third group is based on the fractal theory.

A waveform based coding system can be divided into the following steps: decomposition/transform of the image data, quantization of the transform coefficients, and 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. As a general approach, the subband analysis/synthesis system has been first introduced for one–dimensional data by Croisier [14] in 1976. Smith *et al.* proposed solutions having the perfect–reconstruction property [15]. The extension to 2–D signals has been reported by Vetterli [16]. Later, it has been applied for compression purposes [17]. In subband coding, an image is split into a set of subband images by using a group of bandpass filters [18] followed by critical subsampling. A special case is the transform coding of images among which the discrete cosine transform (DCT) coding techniques led to an international still image compression standard known as JPEG [5]. At compression factors of about 30 to 40 this technique 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. Subband coding of images has been the subject of intensive research in the last years [19–22]. The main artifact at high compression factors (around 50) is due to the Gibbs phenomenon of linear filters and is called *ringing effect*. For low bit rate subband coding [23] (higher than 50) it is of major importance to exploit the existing zero–correlation across the subbands as proposed in [24–26] in order to maintain a good quality. A scheme combining VQ and the prediction of insignificance across the bands has been proposed in [27, 28]. Although it is possible to reduce the ringing effect by an appropriate design of the subband filters [29–32], it is not possible to find linear subband filters which do not have any ringing effect. To avoid this artifact morphological subband decompositions have been proposed [33–35] which lead to good quality decoded pictures at compression ratios as high as 70–80.

The second group of methods is based on second–generation techniques. They attempt to decompose the data into visual primitives such as contours and texures [36, 37]. One approach is to divide the image into directional primitives as proposed in [38]. Segmentation–based coding techniques [39] extract regions from the image data which are represented by their shape and their textural content. Following similar ideas sketch–based image coding [40] 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.* [41, 42] 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.* [43] using multiscale edges. A double layer technique based on multiscale edges and textures has then been proposed in [44].

In general, second–generation techniques become efficient at higher compression ratios (about 50) when compared to other methods.

Iterated functions systems (IFS) theory, closely related to fractal geometry, has recently found an interesting application to image compression purposes. Barnsley [45] and Jacquin [46] pioneered the field followed by numerous contributions [47, 48]. The approach consists in expressing an image as the attractor of a contractive functions system which can be retrieved simply by iterating the set of functions starting from any initial arbitrary image. The form of redundancy exploited is named *piecewise self–transformability.* This term refers to a property that each segment of an image can be properly expressed as a simple transformation of another part of higher resolution. IFS–based still image compression techniques can pretend to very good performances at high compression ratios (about 70–80) as proved by [49, 50].

1.5.3 Very low bit rate video coding

In addition to still image coding, the compression of video signals have to process one more dimension being the temporal coordinate. The existing compression techniques for still images can serve as basis for the development of video coding techniques. Compression algorithms for still images can either be generalized to 3–D signals, or a hybrid approach based on motion compensation can be defined.

The input video data for very low bit rate applications are typically of small size images (approximately 144 $\times$ 176 pixels) with a frame rate of about 5–10 frames/s. The target bit rates vary from 4.8 kbit/s to 64 kbit/s depending on the desired application. In the following, the very low bit rate video compression techniques have been classified into four classes being waveform, object based, model based and fractal coding techniques.

1.5.3.1 Waveform based techniques

Viewing the temporal axis as a third dimension, all the waveform coding techniques developed for image compression can be generalized to the compression of video signals. Only limited work has been published in the use of 3–D transforms for sequence compression [51]. The blocking artifacts at low bit rates, however, make it improper to code image sequences. Three dimensional subband coding of video has been first introduced by Karlsson *et al.* [52]. In this work, standard subband filters are used for the spatial directions while a DCT derived filter bank is applied to the temporal dimension. Variations of this scheme have been reported in literature [53, 54].

The drawback of 3–D subband coding is that the temporal filtering is not performed along the direction of motion. A solution is the combination of the temporal SBC component with motion compensation (MC) [55] as proposed in [56, 57]. This scheme has then been extended by the use of Lattice Vector Quantization and MC with sub–pixel accuracy [58]. The problem of coding the resulting prediction error images also called Displaced Frame Differences (DFD) has been addressed by using linear transforms such as the DCT [59, 60] and by using the wavelet transform [61]. The video coding standards such as MPEG2 [7] and H.261 [8] suggest the use of DCT based algorithms for coding the DFDs. A preprocessing of the DFD using a morphological segmentation has been proposed by Li *et al.* [62, 63].

The application of waveform coding algorithms to very low bit rate video coding have been proposed based on 3–D subband coding [64,65], motion compensated subband coding [66–71] and motion compensated transform coding [12,13].

1.5.3.2 Object based techniques

The promising results obtained with second–generation techniques for still images motivated its extension to image sequence compression. A straightforward solution is to extend the 2–D techniques used previously in a 3–D context. One approach is to perform a 3–D segmentation of a sequence viewed as a 3–D volume. In this optic Willemin *et al.* [72,73] proposed an octree split and merge segmentation as a generalization of the quadtree segmentation previously used in still image coding [36]. Similarly, another technique has been introduced by Salembier *et al.* [74] based on mathematical morphology allowing arbitrary region shapes.

Along the same lines, an object–oriented scheme in which objects are defined as regions with three associated parameters being shape, textural content and motion was proposed in [75]. The parameters are obtained by image analysis based on source models of either moving 2–D object or moving 3–D objects [76].

All these approaches require the transmission of the objects created at the encoder side. The textural content of the objects can be coded efficiently using transform–based techniques similar to those used in block–based methods [77–80]. Typically, the shape information is represented by chain coding of the contour information [81], quadtree shape representation [82,83] or the medial axis transform [84, 85]. Simulation results show that these representations require an important portion of the global bit rate. One solution to reduce this cost is to use more efficient techniques for shape representation such as the geodesic morphological skeleton as proposed by Brigger *et al.* [86] and/or to perform a simplification of the contours by appropriate postprocessing operations prior to their encoding [87]. Another solution is to avoid frequent transmission of contour information by object tracking [88–92]. Finally, a third solution is to define objects with simple shapes which need less bits to be transmitted for their shape representation [93–98].

1.5.3.3 Model based techniques

It is obvious that all techniques developed for compression purposes rely on a certain model. The term model–based coding, however, refers to an approach seeking to represent the projected 2–D image of a 3–D scene by a semantic model. The goal consists of finding an appropriate model with its corresponding parameters.

This technique can be divided into two main steps, namely analysis and synthesis. The analysis block is the most difficult task due to the complexity of the natural scenes. So far, the main effort has been concentrated on simple scenes such as head–and–shoulder sequences [99–101]. The synthesis block, however, is easier because the techniques developed for image synthesis in the field of computer graphics have already addressed this problem. We won't enter into any further details of model–based techniques in this paper. An excellent tutorial exist on this subject by Pearson [102].

1.5.3.4 Fractal based techniques

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 two years. Beaumont suggested a straightforward extension of 2–D approach to 3–D data volumes [103]. In order to reduce the computational burden, Li *et al.* proposed a 3–D approach without domain block search but increasing contractive transformation complexity [104]. Reusens worked on a scheme where sequence volume is adaptively segmented along an octree structure and 3–D blocks coded either by contractive transformation or 3D temporal block matching [93]. Independently, Lazar *et al.* followed the same approach but allowing only contractive transformations [105]. Hürtgen *et al.* introduced a 2–D approach where regions classified as foreground are coded by intraframe fractal approximation [106].

1.5.4 Pre– and post–processing

In a majority of multi-media applications, the materials used for the capture of the data (such as the camera) should be cheap to make it affordable for a large number of users. In addition, compact solutions (miniaturized terminals) are desired. However, the quality of such equipments drops when compared to their more expensive and professional counterparts. It is mandatory to use a pre-processing stage prior to coding in order to enhance the quality of the pictures, and to remove the various noises which will affect the performance of very low bitrate algorithms. Solutions have been proposed in the field of image processing to enhance the quality of images for various applications [107–109]. A more appropriate approach would be to take into account the characteristics of the coding scheme when designing such operators.

Mobile communications is an important application in very low bitrate video coding. Terminals in such applications are usually subject to different motions such as tilting and jitter, translating into a global motion in the scene due to the motion of the camera. This component of the motion can be extracted by appropriate methods detecting the global motion in the scene, and can be seen as a post–processing stage. Results reported in the literature show an important improvement of the coding performance when a global motion estimation is used [110–113].

It is normal to expect a certain degree of distortion of the decoded images for very low bitrate applications. An appropriate coding scheme however, will intruduce these distortions in areas that are less annoying for the users. A further stage could be added to further reduce the distortions due to encoding at very low bitrates, as post-processing operators. Shortly after the introduction of the first coding schemes based on block transforms, solutions were proposed in order to reduce the blocking artifacts appearing in high compression ratios [114–118]. Same approach has been used in order to improve the quality of decoded signals in other coding schemes reducing different kinds of artefacts such as ringing, blurring, mosquito noise, and so on [119, 120].

1.5.5 Products

A number of products currently exist in the market capable of transmitting audio, video and data at bitrates lower than 32 kbps. Most these techniques are based on the principles used in the recommendations H.261 [8, 121], such that they can be used via modems on public switched telephone networks (PSTN), the same way a fax machine operates.

The first product of this kind was the VideoPhone 2500 [122] which was put in the market in 1990. This product was followed by others, namely, British Telecom/Marconi Relate 2000, and COMETH Labs STU–3 Secure. All these products suffer from a low resolution of the images produced both in spatial and temporal domain.

In parallel, a number of activities in form of collaborative projects led to other variants of H.261. Among others, one can mention the SIM3 proposed by COST 211 ter [12], and TMN–4 by ITU–T [13]. This latter reaches acceptable performances at bitrates as low as 8 kbps, for videotelephony sequences. A recent application of this scheme has been implemented in software on 7 DSPs, in the form of a demonstrator capable of encoding audio, video and data at bitrates between 9.6 to 28.8 kbit/s [123].

All these techniques suffer from the welknown artifacts of DCT based hybrid schemes (blockiness and mosquito noise), and do not allow an easy introduction of new functionalities needed for multimedia applications, in addition. The most recent techniques however, produce competitive results with more sophisticated approaches at their preliminary stages, due to the extraordinary amount of fine tuning that has pushed the hybrid DCT coding to the edge of its performance. Unfortunately, simple variants of H.261 do not seem to be able to improve the current state of the art.

1.5.6 Conclusions

The goal of this tutorial has been to provide interested readers with an input table for navigating through coding techniques targeting very low bitrate. The compression of still pictures as well as the compression of video sequences has been overviewed. High compression coding of still pictures has been classified into waveform, second generation and fractal techniques. Video compression techniques have to process one more component which is the temporal coordinate. The techniques developed for still pictures can be either extended to 3–D signals, or a hybrid approach can be defined based on motion compensation. Waveform based techniques can prove efficiency when proper low bitrate oriented features are added. Other techniques especially designed for very low bitrate applications have also been considered namely object–oriented, model based and fractal based techniques. It is delicate to point out the most promising approach though needs are becoming urgent.

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In this paper the compression of visual information at very low data rates is discussed. High compression coding of still pictures can be split into three categories: waveform, second generation and fractal coding techniques. Each coding approach introduces a different artifact at the target bit rates. The objective of the ongoing research is to mask these artifacts as much as possible to the human visual system. 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 ge Very Low Bit Rate Coding of Visual Information --- A Review ---, in ISCAS'95 Tutorial Book, Chapter 1.5. IEEE Press, May 1995. [9] R. Chan, T. Chan, M. Ng, W. Tang, and C. Wong, Preconditioned iterative methods for high-resolution image reconstruction with multisensors, Proceedings to the SPIE Symposium on Advanced Signal Processing: Algorithms, Architectures, and Implementations, Vol. 3461, San Diego CA, July, 1998.Â In SPIE Math. Imagaging: Wavelet Applications in Signal and Image Processing, volume 2569, San Diego, CA, July 1995. [11] G. Fan and W. K. Cham, "Model-based edge reconstruction for low-bit-rate wavelet transform compressed images", IEEE Transactions on Circuits System for Video Technology, vol. 10, no. 1, Feb. ERCEPTUAL coding aims to reduce the bit-rate required to encode an audio signal while minimizing the percep-tual distortion between the original and encoded versions. For musical audio, much of the effort to date has concentrated on generic transform coders which encode the coefcients of an adaptive time-frequency representation of the signal.Â Then, we design an efcient algorithm to infer the object parameters in Section V and derive a very low bit-rate coder in Section VI. We select the best distortion measure and. 1558-7916/$25.00 Â© 2007 IEEE.