MPEG-2 VIDEO ENCODERS FOR BROADCAST APPLICATIONS

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Abstract

Philips Research has been very active in the field of digital video compression for several years. It has recently participated in the specification of the MPEG-2 Video Standard, and has designed a real time MPEG-2 video encoder now available as a Philips product.

Keywords: TV broadcast, MPEG-2 standards, digital video compression, video encoding, real time MPEG-2 processing, MPEG-2 encoder performance, MPEG-2 flexibility.

1. Introduction

Digital video compression is a key technology for the digital broadcasting systems currently being deployed all over the world. In this article, we start from considerations of complete television systems using digital technology, and then we focus on one aspect of the emitter side: video compression and its embodiment in real-time video encoders. Finally, a quick presentation of the current Philips MPEG-2 Video encoder is given.

2. Digital TV transmission systems

2.1. Why digital television systems?

Today's efforts in research and development for complete digital television systems are motivated in particular by the following four reasons:

• Digital provides a high level of guarantee for constant quality delivery. Similarly to Compact Disc, for which quality is excellent even with a large amount of dust or scratches on the disc, reception of digital television provides optimum quality to the user in any realistic transmission condition. Such performances are enabled
by modulation and error protection technologies. For more details about those issues, the reader is referred to the articles presenting cable and satellite specifications for digital video broadcasting in this issue [1].

• Digital provides enhanced flexibility of use. One aspect of this relies directly on the real-time flexibility, that is the possibility of changing any parameter during the operation of the equipment, for some real time video encoders such as the one proposed by Philips Consumer Electronics. This aspect will be the subject of this article. Real time flexibility of other elements of the uplink system is also very attractive; this can be, for instance, flexibility of conditional access systems used for the complete transmission system.

• A very strong reason for digital TV systems to be attractive is the economy on transmission costs made possible for broadcasters and program providers. For instance, MPEG-2 compression technology allows one satellite transponder with 27 MHz bandwidth to broadcast up to 10 MPEG-2 compressed TV programs, whereas over the same channel only one analog program could be broadcasted. Consequently, such efficiency gains enable return on investments in digital compression technology to be achieved quickly.

• The existence of worldwide recognized standards, namely the MPEG-2 Standards for Video, Audio and Systems, is a guarantee for interoperability, and from the service provider viewpoint, for independence with respect to systems suppliers.

In Europe, the DVB (Digital Video Broadcasting) recommendation has also met unanimous acceptance from all European players. In addition to the MPEG-2 standards, it covers scrambling, satellite modulation and cable modulation aspects. European players were program providers, operators, consumer electronics industries and components industries. The setting of the recommendation was achieved very rapidly thanks to the very active involvement of all actors during the DVB process.

2.2. Role of video compression in a digital television system

The role of the video encoder is to represent the video content of a TV program by a few megabits per second, that is in practice in the range of 2–10 Mbit/s. Farther along the emitting chain, the satellite or cable modulator (see reference [1]) will make the transport of this bitstream possible, using only a fraction of the capacity over a conventional analog channel. As a reference, it can be noted that digital video
pictures use a rough bitrate of 166 Mbit/s when entering the video compression unit. This shows clearly how necessary video compression is for a practical use of digital broadcasting.

As mentioned above, compression allows five to ten programs to be transmitted over a conventional 27 MHz satellite transponder, which is currently used to convey only one program in its analog form. More specifically, maintaining excellent picture quality (very close to quality at the studio) five programs can be transmitted, each being compressed at 8 Mbit/s. Another alternative is to transmit ten programs compressed at 4 Mbit/s for standard picture quality which is subjectively equivalent to that of current PAL/SECAM programs, though presenting different kinds of artifacts.

3. MPEG-2 Video standard for compression

3.1. What is the MPEG-2 Video standard?

The MPEG-2 Video standard specifies a bitstream structure (or syntax) and bitstream semantics. In addition it also defines the decoding process to reconstruct decoded pictures from the received bitstreams. It defines neither a decoder implementation nor an encoder implementation. In fact, the MPEG-2 Video Standard, like MPEG-2 Audio and Systems Standards, is meant to be a generic standard: i.e. usable for virtually any application. This implies that bitrate values, picture sizes, number of frames per second etc. are selectable from a large set of values. In addition a large set of algorithmic techniques is defined by the specification and can be used as required by the application. This set of techniques contains, for instance, means to define compatible encoding to generate two received qualities with the same picture resolution, or compatible encoding between standard TV resolution and HDTV resolution.

To organize potential combinations enabled by possible use of different algorithmic techniques and possible support of different coding parameter values as defined by the Video Standard, ‘Profiles’ and ‘Levels’ have been created as part of MPEG-2 Video. A Profile defines the set of algorithmic techniques that have to be supported by a decoder to decode bitstreams corresponding to this Profile. Similarly, a Level defines upper values for algorithmic parameters which must be supported by a decoder corresponding to this Level for a given Profile.

For broadcast applications, the relevant combination of Profile and Level is the so-called ‘Main Profile at Main Level’. The ‘Main Profile’ defines compression tools for excellent efficiency with no added specific feature, to be supported by a
Main Profile compliant decoder. On the other hand, the 'Main Level' means essentially that a compliant decoder shall be able to decode pictures with size up to the one defined by the production format for standard TV (Recommendation 601 of CCIR format), with bitrates of up to 15 Mbit/s. At Main Profile, Main Level, it is also required that a compliant bitstream shall use coded pictures with 4:2:0 sampling format and require a buffer size of less than a given value (in fact 1 835 008 bits). For details about those technical issues, the reader is referred to the articles presenting video compression in this issue [2].

3.2. MPEG-2 has gained worldwide support

The MPEG-2 standard was built with the active participation of worldwide major actors in the fields of integrated circuits, consumer electronics, telecommunications, broadcast services, television broadcast, cable and satellite operations and computers.

The technical excellence of Video, Audio and Systems standards is now known worldwide. On the other hand the generic nature of the three standards enables them to be adapted to specific requirements, and is consequently known to be a very strong advantage for the development and the interoperability of today's and tomorrow's services based on digital audio-video technology.

4. MPEG-2 real time video encoders

4.1. What is an MPEG-2 compliant video encoder?

As mentioned before, the MPEG-2 Video Standard specifies a bitstream structure (or syntax) and bitstream semantics, but certainly does not define the encoding specifications. For digital television applications for which the Main Profile at Main Level is selected, this means that any encoding specification or any encoder implementation that fulfils the standard requirements for the Main Profile at the Main Level in terms of syntax and semantics, and the parameter values constraints for the Main Level, can be considered as compliant.

Consequently, a 'simple' compliant encoder can be built, which will provide poor or medium performance in terms of compression efficiency. Conversely, a 'complex' compliant encoder can use optimally the flexibility of the standards, in terms of coding modes for instance, to provide the best decoded picture quality for a given video bitrate. An important example of the advantage of this situation is that a simple encoder can be designed for consumer applications, and a complex encoder...
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can be used for professional ones, both of them being usable with consumer and professional decoders since these two kinds of decoders implement the same decoding process.

4.2. The Philips-DVS MPEG-2 Video encoder for broadcast applications

As a supplier of complete systems for digital television broadcasting, Philips has developed all the elements of the digital chain and in particular an MPEG-2 Video encoder for broadcast applications.

The Philips MPEG-2 encoder is of course compliant to the MPEG-2 Video standard at Main Profile, Main Level. It compresses picture materials following the recommendation 601 of CCIR (standard definition pictures) with 50 Hz or 60 Hz field rates. For 50 Hz materials the encoder follows the DVB recommendations. In the following the coding performance and the flexibility of the encoder will be discussed.

4.2.1. Performance

Since this product is meant for professional applications, stress was put during the design phase on the encoding efficiency. As part of Philips Research, Laboratoires d'Electronique Philips (LEP) has been significantly involved in the MPEG-2 standardization process from its very beginning in 1991. Consequently, algorithmic expertise exists there to take benefits from the subtleties of the standard and to provide the best encoding performances. As already mentioned, excellent behaviour in terms of compression efficiency is a matter of expert selection of encoding specifications which is clearly not defined by the MPEG standard nor in its scope.

On the other hand, the expertise to build real time MPEG based encoding devices has existed internally at LEP for long, since a so-called 'MPEG 1.5' real time encoder had been built as part of a complete Philips digital television chain in the middle of 1993.

As a logical follow-up, LEP completed in early 1994 the prototyping of a real time MPEG-2 Video encoder which is now known to have an excellent behavior in terms of picture quality. In other words, for a given bitrate it essentially provides the best picture quality, or conversely for a given picture quality, it uses the lowest bitrate.

Some main technical items which explain the performance of the Philips encoder can be summarized as follows.
Very high quality coding is achieved in particular by:

- **Very large range for motion estimation:**
  Motion estimation is able to track objects that cross the screen in half a second. This insures that a proper prediction can be made even for very fast displacements between pictures.

- **Motion estimation adapted to the nature of the motion:**
  Prediction modes based on fields and prediction modes based on frames are supported concurrently. In other words, whatever the nature of the local motion is, interfield or interframe, the embedded motion estimator is able to detect it and measure it accurately. As a consequence, it adapts automatically to the video or the film nature of the picture.

- **Accurate motion estimation:**
  Motion estimation is refined to half pixel accuracy throughout the full search area. Such an accuracy reduces the amount of bits spent to encode the prediction error residue.

- **DCT transformation adapted to the nature of the pictures:**
  Both DCT transforms in fields and in frames are supported concurrently. It means that the best transform, within a field or within a frame, is automatically selected by the encoder. As a consequence, it adapts automatically to the video or the film nature of the picture.

- **Adaptive quantization with respect to eye sensitivity:**
  A proprietary adaptive quantization is implemented, to optimize the subjective picture quality by taking into account the human eye sensitivity. For instance, it is known that on nearly constant areas, the eye is very sensitive to quantization errors. Consequently, for such areas the quantization parameters are decreased to provide more accuracy locally.

- **Bitrate control strategy:**
  A proprietary bitrate control strategy is implemented, enabling decoders to decode video bitstreams seamlessly through bitrate switches at the transmitter side.
4.2.2. Flexibility of use

The Philips MPEG-2 Video encoder is intended to meet a large range of broadcasting requirements. Consequently, relevant encoding parameters can be selected (directly through an RS232 interface, or by the uplink control platform through the Philips MPEG-2 multiplexor). For instance, the user can define his choice of bitrate, and the internal coding format. The main parameters that are selectable are shown in Table I, with related comments for their use.

TABLE I
Main encoding parameter values on the Philips MPEG-2 Video encoder. For details about those technical issues, the reader should refer to the articles presenting video compression in this issue [2]

<table>
<thead>
<tr>
<th>Encoder parameter and supported values</th>
<th>Comments about choice of parameter value in operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitrate: 2 Mbit/s to 15 Mbit/s.</td>
<td>The internal coding format can be selected to provide the desired balance between the coding artifacts and the decrease of the picture resolution.</td>
</tr>
<tr>
<td>Internal coding formats:</td>
<td></td>
</tr>
<tr>
<td>for 50 Hz or 60 Hz video input,</td>
<td></td>
</tr>
<tr>
<td>supported coding formats</td>
<td></td>
</tr>
<tr>
<td>correspond to subsampling ratios</td>
<td></td>
</tr>
<tr>
<td>of 1:1, 3:4, 2:3, 1:2.</td>
<td></td>
</tr>
<tr>
<td>Bidirectional (B) frames: $M = 2$ or 1,</td>
<td>$M = 2$ is recommended in general.</td>
</tr>
<tr>
<td>$M = 1$ means only I and P frames;</td>
<td>$M = 1$ can be used for very fast changing sequences.</td>
</tr>
<tr>
<td>$M = 2$ means one B frame every 2 frames.</td>
<td></td>
</tr>
<tr>
<td>Distance (in number of frames, ‘$N$’)</td>
<td>A smaller value of $N$ decreases the access time in case of channel hopping, but also decreases the coding quality.</td>
</tr>
<tr>
<td>between two consecutive Intra (I)</td>
<td></td>
</tr>
<tr>
<td>supported values for $N$ are:</td>
<td></td>
</tr>
<tr>
<td>4, 8, 12, or 16.</td>
<td></td>
</tr>
</tbody>
</table>
Source, e.g. digital VTR.

- video input

- 50 Hz, 60 Hz, 24 Hz
- 720, 528, 480, 352 pixels per line

**Coding mode supported:**
- 50 Hz, 60 Hz, 24 Hz
- Coding format:
  - 720, 528, 480, 352 pixels per line

**Coding format:**
- 720, 528, 480, 352

**FLEXIBLE AT INPUT!**
- 50 Hz or 60 Hz video input (from video or film source)
- Several coding formats from full to half resolution

**Motion estimation**
- Pixel accuracy
- Very large search area

**Motion estimation**
- Pixel accuracy
- Very large search area

**Motion estimation**
- Pixel accuracy
- Very large search area

**FAST!**
- Tracks fast moving object
- As fast as crossing the screen in 0.5 s

**GOOD FOR YOUR EYES!**
- Adaptive quantization based on eye sensitivity

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**SMOOTH AND FLEXIBLE AT OUTPUT!**
- Bit rate selectable in the range of 2 to 15 Mbit.s⁻¹
- Optimized bit rate strategy for smooth control of image quality

**CONTROL STATION**
- Provides locally decoded pictures for monitoring

**PROFESSIONAL!**
- Provides locally decoded pictures for monitoring

**Fig. 1. Simplified block diagram of the Philips MPEG-2 Video encoder, illustrating its strong points.**
The parameters shown in Table I plus others, such as the status from embedded tests, are reported onto the front built-in LCD display of the encoder, and to the uplink supervising platform through the Philips multiplexor.

Figure 1 provides a synthetic block diagram of the encoder pointing out its strong points.

5. Conclusions

Having been involved from the very beginning in the MPEG-2 standardization process, LEP has specified and built first copies of MPEG-2 real time video encoders for broadcast applications. These encoders have demonstrated very high encoding performances. They have been reshaped into regular Philips products, and are now key elements of a very attractive complete offer from Philips Consumer Electronics for digital television applications.

Philips Research will certainly further exploit its know-how in the field of real time MPEG-2 encoding for broadcast applications, and LEP is already working with other Philips Research and Development Laboratories on new product generations with further improved efficiency and functionalities.

REFERENCES


Authors

Gilles Nocture graduated from Ecole Polytechnique (Paris) in 1984 and from Ecole Nationale des Télécommunications (Paris) in 1986. In 1986, he joined laboratoires d'Electronique Philips, Limeil-Brévannes, France. Since then he has been involved in several projects focusing on recording of compressed digital video signals and bitrate reduction for TV and HDTV signals. From 1991 to 1993, he participated in the specification of the international MPEG-2 Video Standard. He is currently working on research and predevelopment projects dealing with systems for transmission of MPEG compressed programmes.

Thierry Brouste joined Laboratoires d'Electronique Philips, Limeil-Brévannes, France, in 1982. He has been involved in several activities focusing on the definition of new video transmission formats for Europe. In this respect, he has headed several projects aiming at the development of hardware prototypes implementing proposed transmission formats. He is currently working on research and predevelopment projects dealing with systems for transmission of MPEG compressed programmes.