TECHNICAL RESEARCH REPORT

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HDTV: Technology Targets and Research Directions

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HDTV: Technology Targets and Research Directions *

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Abstract

This paper introduces the principles and architectures of high definition televisions (HDTV) and analyzes the functions of HDTV's digital components. It compares the current analog HDTV systems with the prototypes of digital HDTVs. It then summerizes the latest developments in digital HDTV technologies and identifies current technology targets. Finally, this paper predicts and proposes future research directions in digital HDTVs.

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1 Introduction

The concept of High Definition Television (HDTV) conceived two decades ago due to the need to improve TV picture quality for different applications. HDTV started in the early 1970's at the NHK (The Japan Broadcasting Corporation) in Japan [6]. Many research activities on HDTV have been going on regarding the broadcast standards, HDTV system configurations, image processing techniques and HDTV's potential applications. HDTV offers much improved image quality and a wider picture format. It has many potential applications in industries, education, and of course entertainment [2].

Two HDTV broadcasting systems exist in the world today, the Multiple Sub-Nyquist Sampling Encoding (MUSE) in Japan and the High Definition Multiple Analog Components (HD-MAC) in Europe. The later is the result of the Eureka 95 project [20]. The two systems belong to the same category; they are analog systems and use similar technologies. Both systems meet the International Radio Consultative Committee (CCIR) Recommendation 709 except in the scanning parameters which have not been specified by the committee.

The HDTV research in the U.S. is different from that of its counterparts. The HDTV systems undergoing research in the U.S. are digital systems unlike the two existing systems. The leading candidates of the Advanced Television (ATV) include systems using digital bit-rate reduction coding schemes and other advanced image processing techniques [10] [24]. Since these systems are fully digital, they offer flexibility in incorporating with computers and are open to new technologies as well as new services. Research on several proposed standards of broadcasting is still going on.

Some open questions still exist in HDTV research. The foremost is how to achieve better compatible horizontal and vertical resolutions [24] as the new TV system is going to have a wider picture format with a 16:9 width to height ratio. The proposed ratios of improved resolution with respect to that of current TV system are 2:1 vertically and 2.5:1 horizontally [24]. Obviously, the amount of information to be processed is at least twice as much as current TV systems. This poses a new technical challenge. Secondly, compatibility is an issue in HDTV research. The new HDTV broadcast should be compatible with the current TV broadcasting in order for the users to receive TV programs produced in one system with the TV sets manufactured for another system. This is similar to the coexistence and transition from B/W TV systems to color TV systems. Next, a unified HDTV broadcasting standard needs to be settled. With the rapid developments in information science and computer technologies, the HDTV broadcasting standard should adapt to future technical changes. The Federal Communications Commission (FCC) is expected to establish a terrestrial HDTV broadcast system in the near future [9] [14].

With the rapid advances in HDTV technologies, it is important to have a clear understanding of the stages of the current technologies. Despite some effort has been made on this, it is still necessary to clarify the technical targets and research directions in HDTV for the next few years. This article is intended to provide a systematic account and analysis of HDTV technologies.

The rest of this paper is organized as following. The next section introduces the principles and architectures of HDTV systems, MUSE, HD-MAC and digital HDTVs, then compares these systems. The third section summerizes the techniques used in digital HDTV and identifies the technology targets. The fourth section suggests future directions on HDTV research. The last part concludes this paper.

2 Current HDTV systems

The MUSE in Japan and HD-MAC in Europe are the two existing HDTV systems in the world. The development of the two systems was aimed at obtaining the best picture quality, matching with other media such as CATV, VCR and videodisk, and being compatible with current TV broadcasting systems via satellite broadcasting. The technologies in MUSE and HD-MAC are similar in many aspects. They all employ frame/field subsampling for bandwidth compression and adopt analog, sampled value transmission as their transmission format with digital image control signals. Both systems use frequency modulation (FM) as their modulation format.

2.1 MUSE and HD-MAC systems

The most important technical bases for MUSE are bandwidth compression using multiple subsampling and compensation, and synchronization providing an accurate resampling phase. In the encoder of a MUSE system, the analog image signals are prefiltered and digitized, the digital signals are then processed through two channels, a motion channel and a stationary channel. Figure 1 [20] illustrates the structure of a MUSE encoder. The stationary parts of a picture first pass the Field Offset Subsampling unit then the Frame Offset Subsampling unit, while the motion parts go through the Frame Offset Subsampling unit only. The original sampling rate is 48.6 MHz, with first subsampling rate at 24.3 MHz and the second subsampling rate at 16.2 MHz. A motion detection technique is employed to switch processing between the motion and stationary parts of the image. Based upon the motion detection and relevant control signals, the compressed images from the two channels are added pixel by pixel to yield the image to be combined with audio signals for generating a MUSE output. The output is then modulated and sent into the transmission channel. This process is reversed in the MUSE decoder [Figure 2] to reproduce the TV images. A recent book by NHK [22] presents HDTV standards, image technology, transmission and recording technology of analog HDTV. Its analysis is based on the MUSE system.

The HD-MAC system uses similar technologies as the MUSE system does although it has a different system configuration. In the HD-MAC encoder, sub-band prefiltering and subsampling are performed and the results are sent to the shuffling units. The outputs from the different shuffling units are selected according to the output signal from the motion vector detection unit to be further encoded and sent to the transmission channel. The input to the motion vector detection comes from the sub-band prefilter with the medium frequency. Hence, the sampling patterns are chosen based on the level of image motion detected. The image control of HD-MAC is blockwise other than the pixelwise format of the MUSE system. The decoder of the HD-MAC system reverses the above process to reconstruct TV pictures.

Although MUSE an HD-MAC are supported by digital technology, they actually are analog systems since the final signal transmissions are analog. The quality of transmission may degrade as the current broadcast does. This is one of the limitations of the available technology when the two systems were first developed.

2.2 Digital HDTV systems

Unlike the MUSE and HD-MAC systems, the prototypes of HDTV systems developed in the U.S. are based on digital technologies and low bit-rate data

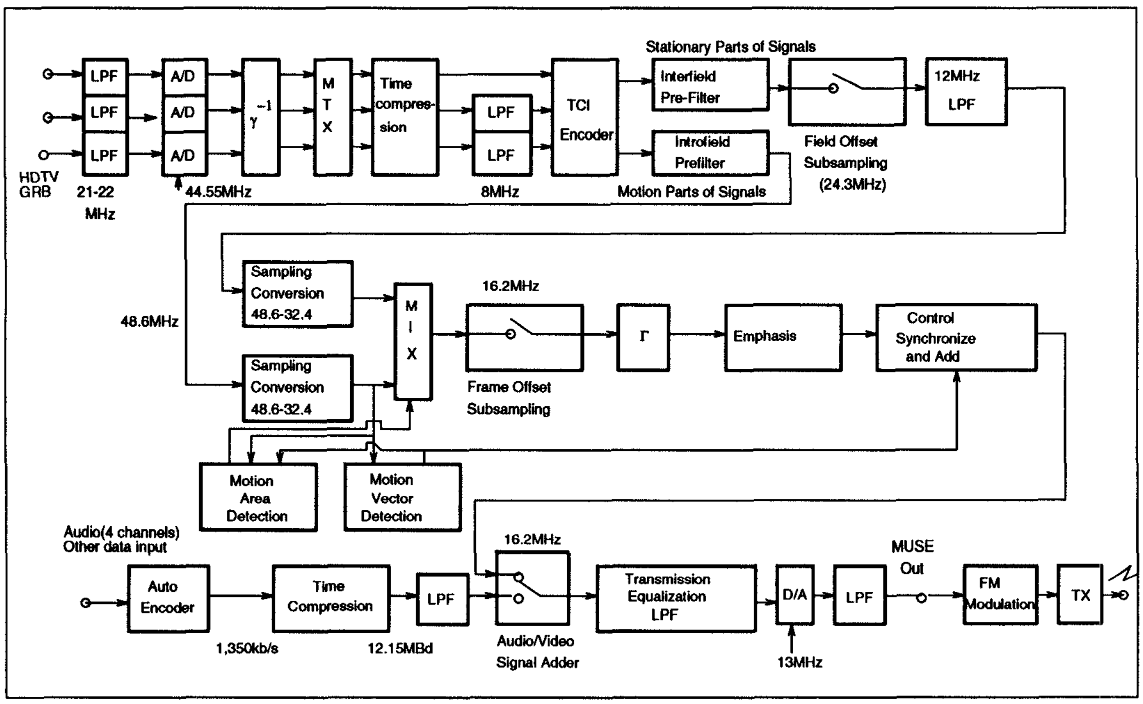

Figure 1: MUSE encoder

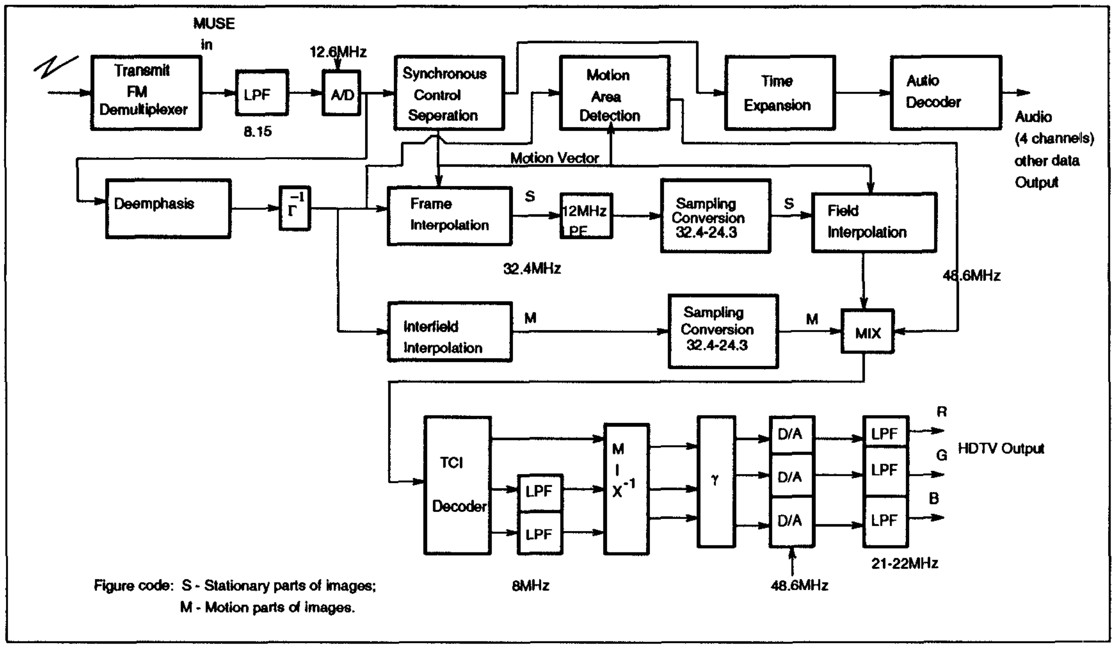

Figure 2: MUSE decoder

compression techniques. The transmission channel is going to be digital as well. Four different digital HDTVs are being tested and evaluated [28]. The block diagrams [10] shown here are intended to prove a general idea about the structures and principles of digital HDTV. As we can see from the following, reducing the temporal and spatial redundancy of video signals is one of the major tasks in HDTV technologies.

Figure 3 shows the structure of a HDTV encoder. The "new picture" is the digital video input to the systems. The "difference picture" is obtained through subtracting the predicted picture from the video input, i.e., the "new picture". Since video pictures are usually related in a sequential manner, the difference picture contains much less information than the original picture does especially when the changes between two images are small and slow. Temporal redundancy is reduced by transmitting only the difference of two consecutive images.

The difference picture is sent through transform coder to further reduce its spatial redundancy. The image is divided into blocks of eight by eight picture elements. The coefficients generated by transform encoder represent

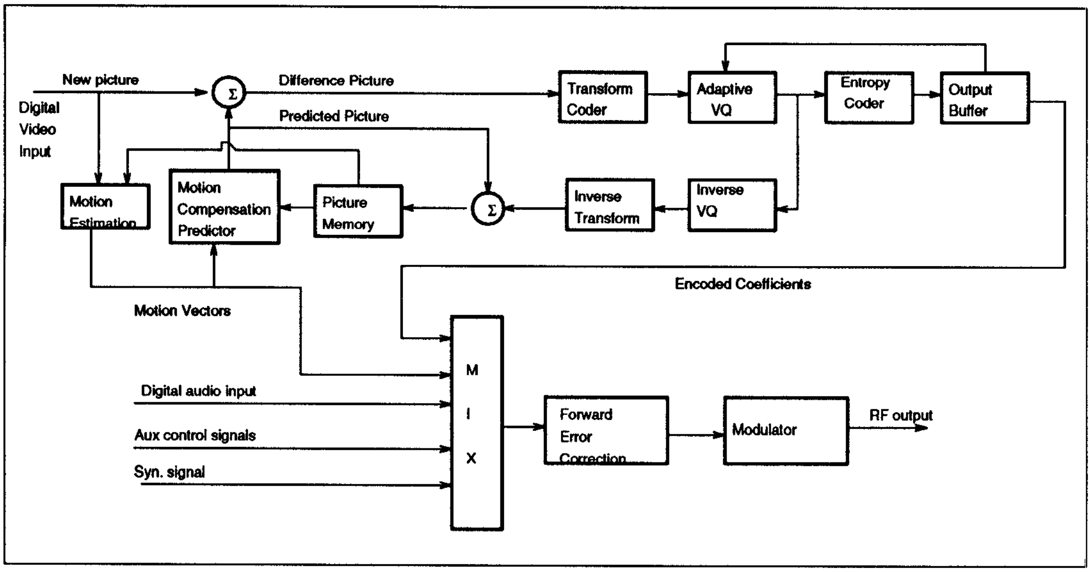

Figure 3: Digital HDTV encoder

different frequency components of the picture, and the amplitudes of these coefficients represent the strength of different frequency components along the vertical and horizontal directions. These coefficients are small when the spatial redundancy is high. One approach of data compression is to roundoff those coefficients smaller than a predetermined threshold.

Adaptive quantizer, entropy coder and buffer work together to produce encoded coefficients for transmission at a fixed low bit-rate. Their basic function is to keep the data rate to be transmitted low while maintaining the required picture quality. The output rate of the buffer is fixed; the buffer sends feedback signals to the adaptive quantizer to adjust the levels of quantization in order to keep the information flow at a predetermined constant rate.

The inverse quantizer and inverse transform blocks reverse the processing in adaptive quantizer and transform coder. The output of the inverse transform is a reconstructed difference picture which is added by the predicted picture and then fetched into the picture memory unit for motion estimation of the next new picture. At the same time, the outputs of the picture memory unit and the motion vectors are sent to the motion compensated predictor to produce a predicted picture for the new picture to come. The encoded

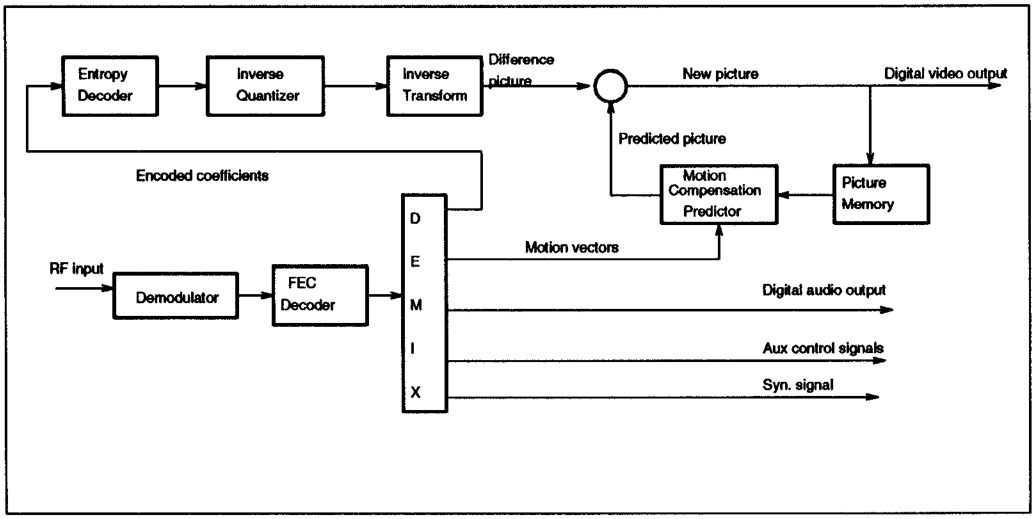

Figure 4: Digital HDTV decoder

coefficients, motion vectors together with other signals such as digital audio, control data and synchronization go to modulator through a multiplexer and a forward error correction unit (FEC) to produce the RF output.

The digital HDTV decoder is illustrated in Figure 4, its functions are the inverse of those of the encoder. The input RF signals are first demodulated, sent through FEC decoder and then are separated into different signals by the demultiplexer. The encoded coefficients are sent to entropy decoder, inverse quantizer and inverse transform unit which are identical to those in the encoder. The motion compensated predictor and picture memory units are the same as those in the encoder, too.

The updated information from the inverse transform unit is combined with the predicted picture from the motion compensated predictor to reproduce a new picture. The new picture is sent to the digital video output channel for display and to the picture memory to generate the predicted picture for the updated information to come. This process repeats to reconstruct a sequence of pictures.

Digital audio, control data and synchronization signals are forwarded to the relevant units of the HDTV receiver. The sync signal guarantees that the output video picture matches the input one and coordinates the operation of different units in both the encoder and decoder.

2.3 Comparison of HDTV systems

The above HDTV systems differ mainly in the following:

- **Bandwidth compression**
  The MUSE and HD-MAC systems use multiple subsampling for bandwidth compression; the digital HDTV employ advanced digital techniques, such as DCT transform, vector quantization and entroy coding for image compression .

- **Transmission channels**
  The MUSE and HD-MAC systems are hybrid systems and send out analog FM signals; digital HDTV systems transmit digital FM signals through the transmission channels.

Digital HDTV systems offer flexibilities and high potentials in future applications not found in the analog systems. Digital HDTVs can be incorporated with computers and are open to new technologies. With the developments of ATM and B-ISDN networks [7], digital HDTVs are feasible to offer two-way interactive services, multiple displays and all kinds of bells and whistles.

3 Image processing for HDTV

Digital image processing is the key to digital HDTVs. The above analysis shows that the major differences between the current HDTV systems and the digital HDTVs are how the signals of images are processed. In both MUSE and HD-MAC systems, the bandwidth is compressed through multiple subsampling. While in digital HDTV, the information is compressed by reduction of temporal and spatial redundancies through source coding. We can implement different transform algorithms and coding schemes in the encoders and decoders for data compression. The basic techniques used in digital HDTV include [18, 15]:

- Source coding:

  1. Motion prediction/compensation;
  2. Transform coding;

3. Quantization;
4. Entropy coding;
5. Buffer.

- channel coding:

1. Multiplexing;
2. Error detection/correction.

- modulation.

Data compressing techniques are crucial in HDTV technologies which provide the means of reducing the amount of data to a manageable level. Since there are no available image compression models similar to those in voice data compression such as linear predictive coding (LPC) and code-excited linear prediction (CELP) models, transform and subband coding methods are widely used in image processing. As we observed earlier, the transform unit and entropy coder are incorporated into the digital HDTV system for this purpose. Redundancy in HDTV signals is reduced through transform and entropy coding. One good source of references on signal compression is a paper written by Jayant [12]. An excellent book by Gersho and Gray [5] treats both scalar and vector coding and provides a rich collection of references. HDTV signal has a bit-rate of over a gigabit per second before compression based on the sampling rate and the total number of bits per sample. Compressing HDTV signals to the range of 20Mb/s can facilitate simulcasting the HDTV version of signals into a regular NTSC channel. Higher bit rate transmission are appropriate for high quality HDTV signal transmission through ISDN channels via satellites. To obtain the highest signal quality at the lowest bit-rate possible is the target of research on source coding in digital HDTV.

A widely used technique in video is two dimensional discrete cosine transform (2D-DCT) on interframe motion compensation. Since the introduction of DCT in 1970's, a considerable amount of research has been performed on architectures, algorithms and implementations. Computation of the DCT and inverse DCT at a very high data throughput is essential to HDTV application. Currently, a 8×8 2-D DCT processor based on low cost 2 μ CMOS technology can handle a data rate of higher than 55MHz [23]. To generate fast algorithms and efficient VLSI implementations with only local data communications are the current research targets in the VLSI communities.

4 Research directions

In discussion of research directions, it is impossible to be exhaustive and/or very accurate in predicting what technology is going to succeed next in this fast developing and highly interdisciplinary world of technologies. The large scope of digital HDTV research and lack of broadcasting standards make difficult to arrange a truly unified frame work on the developments of the latest technologies. However, we make effort to at least tackle parts of this aspect.

Time-frequency analysis
Wavelets, a new technique in time-frequency analysis, may reduce the redundancy of video both in time and in space domain. The multiresolution property [19], time and frequency localization ability of wavelets have caught strong attention in signal processing communities and many other fields in the past several years. Wavelet filter bank is a natural setting for dealing with video and audio signals. The coarse components (lower resolution parts) of image signals can be used in motion estimation and detection [27] while the fine components at different scales can be combined regressively to reproduce images of increasing details. Akansu and Haddad provide an unified treatment about transforms, subbands and wavelets theories on multiresolution signal decomposition [1]. The relation between wavelet transform and multirate filter banks can be found in a recent book by Vaidyanathan [25]. Wavelet approach is likely to be a powerful tool in the analysis of time varying systems since it offers adjustable scales for analyzing the systems.

Motion detection and compensation
Motion detection and motion compensation are used to reduce the temporal redundancy of the video images, which provides the motion vector used to generate the predicted image. There are two major approaches so far, time domain and frequency domain. Current research is on the modeling of motion and efficient algorithms to abstract the motion vectors [4, 27, 26, 11]. An

algorithm for the estimation of block motion vectors is proposed [17] based on motion-field and pixel subsampling.

Vector quantization and image coding
Vector quantization (VQ) is known to have been successfully used for DCT-VQ coding in image and voice signal processing. VQ is most efficient at very low bit-rate since a reasonable size of the VQ codebook can be used [5]. A VLC parallel entropy coding systems [16] and parallel sub-channel transform coders [8] are introduced to facilitate real time implementation. Further research is needed in better understanding the tradeoff and interaction between VQ and entropy coding. The research on adaptive vector quantization will facilitate this research. It is feasible to work on adaptive vector quantization using concepts and methodologies from control system theory. Research on subband coding aimed at B-ISDN transmission [3] is also on its way.

Robustness
Reliability and robustness are the important factors for providing continuous service even when many bit errors occur due to poor signal reception or in the presence of other interferences. The HDTV systems have to keep synchronization which is a basic requirement. One of the research activities is on improving video coding techniques which are robust to a high noise/signal ratio and other interferences.

Performance measures
Standards of performance are also needed in judging the quality of HDTV. The current standards are lack of unified models for performance evaluation. The appropriate standards can facilitate the design and judgement of HDTV systems. Criteria for optimal coder designs still need to be set.

Broadcasting standards
The broadcasting standards of digital HDTV are still unsettled. Some researchers have been focusing on transition systems, enhanced definition television systems (EDTV) between NTSC and HDTV systems [13]. The major parties of HDTV research in the US have agreed to work together to develop high definition TV systems and sets. The standards need to be set in order to set up a unified broadcasting system compatible with the current NTSC

system.

Hardware implementations
Equally important are the hardware implementations in HDTV. DSP chips with high performance/cost ratio are going to accelerate the development and commercialization of HDTVs. DSP technology in term of number of instructions per second is growing exponentially and is unlikely to saturate in the near future. The typical per chip capability is expected to increase ten-fold, from 25mi/s to 250mi/s, during a five year period from 1990 to 1995 [12] with the manufacturing cost going down. Quadrature mirror filters (QMFs) are found appropriate in terms of filter reconstruction, quantization errors and VLSI implementation [21]. We need to generate fast parallel algorithms and efficient VLSI designs with localized data communications. The continuous developments in DSP shall have direct impacts on digital HDTV systems.

HDTV camera sensitivity
One of the areas in development is in HDTV cameras. Due to the wider picture format, the f-stop in a HDTV camera must be increased by two stops to keep the right amount of exposure while maintaining the same depth-of-field as the current conventional TV cameras do. The HDTV camera tube has to be four time as sensitive as those of current standard TV cameras. The research for new camera tubes is underway stimulated by the recent discovery of avalanche effect in photoelectric conversion films which increase the efficiency of photoelectric conversion to as much as tenfold [22].

5 Conclusions

This paper presents the history and the latest developments of HDTV. It provides an explanation on the principles of HDTV and compares the differences between the existing systems and the prototypes of digital HDTVs. Based on the review and analysis of image processing techniques, the paper points out current technical targets in digital HDTV. Finally, it predicts the research directions in HDTV and in its related fields for the next several years.

Digital HDTVs will continue to be a field of research in future, and are going to revolutionize the current TV systems in the next several years. Digital HDTV will certainly enrich people's life to a new extend and soon find wide applications in science, education, industries, commerce, entertainment and other emerging fields. Stimulated by current research heavily invested by both the government and communication industries on networks and information systems, we can predict, digital HDTV is going to be an important component in the infrastructure of future electronic information highways.

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