Advanced Telecommunications and Signal Processing

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Introduction

The analog television system was designed nearly 60 years ago. Since then, there have been significant developments in technology, which are highly relevant to the television industries. To exploit this new technology in developing future television systems, the research areas of the program previously focused on a number of issues related to digital television design. As a result of this effort, significant advances have already been made and these advances have been included in the U.S. digital television standard. Specifically, the ATSP group represented MIT in MIT's participation in the Grand Alliance, which consisted of MIT, AT&T, Zenith Electronics Corporation, General Instrument Corporation, David Sarnoff Research Center, Philips Laboratories, and Thomson Consumer Electronics. The Grand Alliance digital television system served as the basis for the U.S. Digital Television (DTV) standard, which was formally adopted by the U.S. Federal Communications Commission in December 1996.

The digital TV system based on this standard has been deployed successfully. In 2006, digital television receiver sales exceeded analog television receivers in both number and dollar volume in the U.S. The analog terrestrial TV transmission was discontinued in the United States in June, 2009.

The standard imposes substantial constraints on the way the digital television signal is transmitted and received. The standard also leaves considerable room for future improvements through technological advances. Future research will focus on making these improvements. The digital television system is a major improvement over the analog television system. The next major improvement over the digital television system is likely to be in the introduction of 3-D television. We are currently exploring methods for efficient transmission of 3-D TV signal.

The specific research topics where we made some progress are as follows:

1. Transforms for Prediction Residuals in Video Coding

Sponsor: Advanced Telecommunications Research Program

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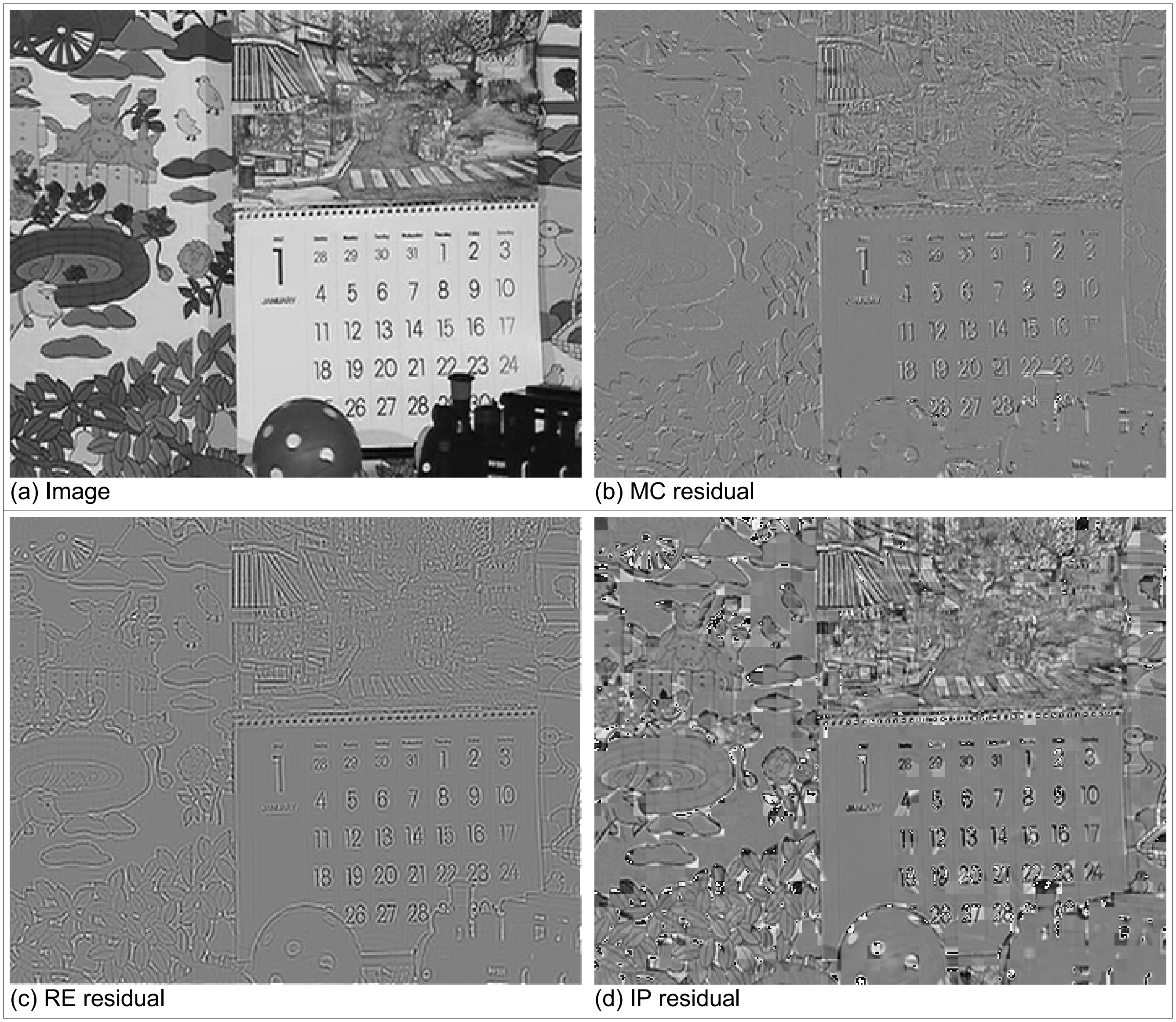
An important component of image and video compression systems is a transform. A transform is used to transform image intensities. A transform is also used to transform prediction residuals of image intensities, such as the motion compensation (MC) residual, the resolution enhancement (RE) residual in scalable video coding, or the intra prediction (IP) residual in H.264/AVC. Typically, the same transform is used to transform both image intensities and prediction residuals. For example, the 2-D Discrete Cosine Transform (2-D DCT) is used to compress image intensities in the JPEG standard and MC-residuals in many video coding standards. Another example is the 2-D Discrete Wavelet Transform (2-D DWT), which is used to compress images in the JPEG2000 standard and high-pass prediction residual frames in inter-frame wavelet coding. However, prediction residuals have different spatial characteristics from image intensities [1-3], [9]. In this research, we analyze the differences between the characteristics of images and several types of prediction residuals and propose transforms that are adapted to the characteristics of MC and RE residuals.

Recently, new transforms have been developed that can take advantage of locally anisotropic features in images [4-8]. A conventional transform, such as the 2-D DCT or the 2-D DWT, is carried out as a separable transform by cascading two 1-D transforms in the vertical and horizontal dimensions. This approach favors horizontal or vertical features over others and does not take advantage of locally anisotropic features present in images. For example, the 2-D DWT has vanishing moments only in the horizontal and vertical directions. The new transforms adapt to locally anisotropic features in images by performing the filtering along the direction where image intensity variations are smaller. This is achieved by resampling the image intensities along such directions [5], by performing filtering and subsampling on oriented sublattices of the sampling grid [7], by directional lifting implementations of the DWT [4], or by various other means. Even though most of the work is based on the DWT, similar ideas have been applied to DCT-based image compression [8].

In video coding, prediction residuals of image intensities are coded in addition to image intensities. Many transforms have been developed to take advantage of local anisotropic features in images. However, investigation of local anisotropic features in prediction residuals has received little attention. Inspection of prediction residuals shows that locally anisotropic features are also present in prediction residuals but have different characteristics from the ones in images. Unlike in image intensities, a large number of pixels in prediction residuals have negligibly small amplitudes because these pixels were predicted well. Pixels with large amplitudes concentrate in regions which are difficult to predict. For example, in MC and RE residuals, such regions are object boundaries, edges, or highly detailed texture regions. Since prediction typically removes the more easily predictable parts of the image signal, the remaining residual signal contains the parts which are difficult to predict, and the spatial characteristics of this signal are different from the characteristics of the original image signal.

A significant difference between the characteristics of images and MC or RE residuals exist in regions which contain object boundaries or edges [9-10]. In these regions, the rapidly changing pixels along the boundary or edge in the original image can not be predicted well and large prediction errors concentrate along these structures. These structures are 1-D structures and the residuals concentrating on these structures form local regions in MC and RE residuals with 1-D signal characteristics. Such local regions with 1-D characteristics can be easily seen in the MC and RE residuals in Figure 1. Boundary or edge regions in images, on the other hand, have typically smooth structures on either side of the boundary or edge and their characteristics are 2-D. The described difference between the characteristics of images and MC or RE residuals can also be quantified using an auto-covariance analysis [9].



(a) Image
(b) MC residual
(c) RE residual
(d) IP residual

Figure 1. Image and several types of prediction residuals obtained from the same image.

The described 1-D signal characteristics of MC and RE residuals in regions with object boundaries or edges indicate that such regions can be better represented with transforms that have 1-D basis functions with support aligned with the direction of the local 1-D structure. Specifically, 1-D directional transforms can be used for the compression of such regions. To evaluate the effectiveness of these transforms, an H.264 codec (JM 10.2) has been modified to include these transforms. The codec has access to 1-D directional transforms and the conventional 2-D DCT and can choose any of these transforms adaptively for each local region.

Experimental results with the modified codec have shown that 1-D directional transforms can be useful for the compression of MC and IP residuals. Specifically, bitrate savings upto 25% were achieved [10]. Bitrate saving depends on many factors, especially the characteristics of the video content. Video sequences with many objects, edges and sharp content typically achieve higher bitrate saving.

Potential areas for future research include the investigation of other types of prediction residuals, such as the disparity compensated prediction residuals in 3-D video coding, and the direct application of the proposed 1-D transforms on resolution enhancement residuals in scalable video coding. Another area for future research is to design new algorithms to code the coefficients of the proposed 1-D transforms more efficiently. In our experiments, we did not design coefficient coding methods that are adapted to the characteristics of coefficients of the proposed transforms. Instead, we changed only the scanning pattern and the remaining coding method was not modified.

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2. Using Enhancement Data to Deinterlace 1080i HDTV

Sponsor: Advanced Telecommunications Research Program

Project Staff: Andy Lin

Interlaced scan has always been an important aspect of broadcasted television. Established in the 1930’s, interlaced scan was originally a solution to reduce flicker in televisions, without doubling the bandwidth or reducing the quality of video. Today, interlaced scan is outdated, as televisions no longer require interlacing to reduce flicker. Interlaced video leads to unsightly artifacts if not deinterlaced properly. Therefore, modern displays must deinterlace interlaced high definition television. However, high quality deinterlacing can be quite computationally intensive.

U.S. over-the-air (OTA) broadcasting changed to an all-digital format in June, 2009. The television industry is ready for the implementation of a system, which will improve high definition television (HDTV), in order for HDTV quality to migrate towards a new standard. This receiver compatible system will allow for an additional enhancement stream, which will enable new HDTVs to easily deinterlace 1080i streams. Older HDTVs will still be able to view HDTV by ignoring this stream and decoding the original 1080i stream.

The receiver compatible system is advantageous because it shifts computing costs from the receiver to the transmitter. There are far more receivers than transmitters, thus the net cost is reduced dramatically. Moreover, the receiver compatible system has access to the original video, allowing for the final result to have better quality than traditional deinterlacing systems.

We developed an algorithm to compute an enhancement stream that has a small enough bit-rate, yet still improves video quality significantly, compared to traditional systems. Using a small bit-rate stream allows us to propose using the receiver compatible deinterlacing system alongside mobile digital television. An implementation of an efficient small bit-rate receiver compatible enhancement stream is possible for 1080i HDTV streams. If decoded properly, this efficient small bit-rate stream yields results that are mathematically and visually superior to traditional deinterlacing algorithms. The results of this research were recently reported in [6, 7].

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