

摘 要

随着高分辨率数字广播、高密度激光数字存储媒体、无线宽带多媒体通讯、互联网宽带流媒体等重大信息产业应用需求的日益迫切，新一代高效视频编码技术及技术标准已经成为近年来学术界与工业界的研究热点之一。本文针对以往视频编码中变长编码技术在编码效率、友好实现特性、抗误码等方面的不足进行了深入的研究，提出了具有高编码效率、高吞吐率、抗误码性能显著提高的三项变长编码技术，并探讨了在实际应用中复杂性可接受的前提下变长编码技术所能达到的编码效率上限。其中，所提出的基于上下文的二维变长编码技术 C2DVLC 已经被国家 AVS 视频标准采纳。具体地，本论文的主要研究内容如下。

第一，以往变长编码技术由于缺少对 DCT 系数统计特性的挖掘与利用，因而编码效率较低。针对这一问题，本文对高分辨率视频编码中 8×8 DCT 系数的统计特性进行了深入分析，提出了相应的上下文建模方法，并进而提出了基于上下文的二维变长编码技术 C2DVLC。具体地，针对零系数游程 *Run* 与非零系数 *Level* 联合概率分布的变化，C2DVLC 采用了多个上下文状态以及多个 2D-VLC 码表，通过上下文状态以及码表的自适应切换实现对 $(Run, Level)$ 概率分布变化的匹配。其中，每个上下文状态及其码表被设计成与 $(Run, Level)$ 概率分布变化过程中的一个典型概率分布相对应。C2DVLC 根据已编码 *Level* 幅值的最大值进行上下文状态以及码表的切换，此操作可通过查表完成，实现简单。C2DVLC 采用 Exponential-Golomb 码进行编码，这保证了多码表只需较低的存储空间。实验结果表明，在所测试视频上，C2DVLC 相比于 2D-VLC 码率最高节省 16.11%，码率平均节省 8.38%。C2DVLC 已经被国家视频编码标准 AVS1-P2 (GB/T 20090.2) 采纳。

第二，变长编码中上下文建模的引入带来了编码效率的提高，但同时也导致解码数据吞吐率的下降。吞吐率下降的原因在于目前的上下文建模属于顺序依赖上下文建模。顺序依赖上下文建模中紧邻符号之间的上下文依赖关系导致解码端上下文建模与变长码解码必须串行执行。为此，本文提出了层次依赖上下文建模。层次依赖上下文建模 HDCM 充分挖掘了 DCT 系数的统计特性以提高编码效率，同时打破了紧邻符号之间的上下文依赖关系，这使得上下文建模与变长码解码的并行执行成为可能。提出的基于层次依赖上下

文建模的变长编码技术 HDCMVLC 采用 HDCM 建模与 Golomb-Rice 码实现了 DCT 系数的高效编码。实验结果表明,在所测试视频上, HDCMVLC 具有与 H.264/AVC CAVLC 相当的编码效率,但解码吞吐率最大可提高 86.12%。

第三,可逆变长编码是一种重要的抗误码编码技术,但以往的可逆变长编码在误码率较高时其抗误码性能有限,同时由于缺少上下文建模而编码效率较低。为此,本文提出了基于上下文的可逆变长编码技术 CRVLC。CRVLC 采用层次依赖上下文建模 HDCM,可逆 Golomb-Rice 码以及数据分割技术。HDCM 不仅有效地挖掘了 DCT 系数的统计特性提高了编码效率,同时在数据分割技术的配合下实现了逆向解码中上下文建模的重建,从而使得基于上下文的可逆变长编码的可逆解码成为可能。所提出的数据分割技术带来了抗误码性能的提高。CRVLC 通过层次依赖上下文建模,可逆 Golomb-Rice 码以及数据分割技术的相互配合,实现了高抗误码性能、高编码效率的可逆变长编码。实验结果表明,在所测试视频上,CRVLC 相比 2D-RVLC 抗误码性能最大可提高 2.49dB,平均码率节省 4.21%。

第四,用于 DCT 系数编码的基于上下文的变长编码技术可获得的最高编码效率是什么,是一个非常值得探讨的问题。本文设计了基于上下文的自适应变长编码技术 CBAVLC,其设计目标是探寻在实际应用中复杂性可接受的前提下基于上下文的变长编码技术可达到的最高编码效率。为此,CBAVLC 采用 HDCM 上下文建模。HDCM 是一种基于先验知识的上下文建模方法,我们的分析认为其建模性能是近优的。特别地,CBAVLC 采用自适应编码技术在线估计编码进行中每个上下文状态下的概率分布,并据此选择最优的 Golomb 码进行编码。可以认为,CBAVLC 接近了在实际应用中复杂性可接受的前提下可获得的最高编码效率。实验结果表明 CBAVLC 相比 CAVLC 其编码效率略有提高。这说明,CAVLC, C2DVLC, HDCMVLC 等基于上下文的变长编码技术其编码效率已经接近实际应用中可达到的最高性能。

关键词: 视频编码; 熵编码; 变长编码; 上下文建模

Abstract

Along with increased requests for important applications, e.g., high-resolution digital broadcasting, high-density laser-digital storage media, wireless broad-band multimedia communication, and internet broad-band streaming media, new generation video coding techniques and standards have been one of the most active research areas in the academic and industrial societies in recent years. In this dissertation, variable length coding (VLC) techniques for DCT video coding systems are investigated to deal with the inefficiency of traditional VLC techniques in coding efficiency, friendly implementation, and error resiliency. Three context-based variable length coding techniques are proposed to obtain high coding efficiency, high decoding throughput, and high error resiliency. And the maximal coding efficiency of context-based VLC, achievable under acceptable complexity of practical applications, is also discussed. In particular, the proposed context-based 2-D variable length coding, C2DVLC, has been adopted by China video coding standard (AVS). The detailed descriptions for these techniques are as follows.

First, traditional variable length coding techniques for video DCT blocks have relative low coding efficiency, since statistical properties of DCT blocks are not fully explored. To resolve this problem, this paper fully analyzes these properties and proposes a context modeling technique to effectively explore them. Further, a context-based 2-D variable length coding technique, C2DVLC, is proposed for video DCT blocks. Specifically, to capture the distribution variation of $(Run, Level)$, C2DVLC uses multiple contexts and multiple 2D-VLC tables, where each context and the related table are designed to match one of the typical distributions which are observed in the distribution variation. By adaptively switching the contexts and the tables, the distribution variation is captured. C2DVLC uses the maximal magnitude of previously coded $Levels$ to switch the contexts and the tables. It can be realized by table lookup, so the implementation is easy. C2DVLC uses Exponential-Golomb codes, which makes the table storage space low. The experimental results show that on the test videos

C2DVLC has maximal 16.11% and average 8.38% bit-rate savings relative to 2D-VLC. C2DVLC has been adopted by AVS1-P2 video coding standard.

Second, context modeling brings further coding efficiency for variable length coding, but meanwhile it lowers decoding throughput. The reason is that the existing context modeling techniques are tightly sequential dependency context modeling, where context dependency between successive symbols makes context modeling and variable length decoding sequentially executed at the decoding side. So hierarchical dependency context modeling, HDCM, is proposed to resolve this problem. HDCM fully exploits the statistical properties of DCT blocks, which brings high coding efficiency, and at the same time it breaks context dependency between successive symbols, which enables the concurrency of context modeling and variable length decoding. The proposed HDCM-based variable length coding technique (HDCMVLC) uses HDCM and Golomb-Rice codes to realize high efficient coding of DCT blocks. The experimental results show that on the test videos HDCMVLC has the similar coding efficiency as CAVLC but has maximal 86.12% decoding throughput improvement.

Third, reversible variable length coding (RVLC) is an important error resilient coding technique. But traditional RVLC has no context modeling supported, so its coding efficiency is low. And meanwhile it has limited error resilience performance in high error rates. So a context-based reversible variable length coding technique, CRVLC, is proposed to achieve high coding efficiency and high error resiliency concurrently. CRVLC uses HDCM, reversible Golomb-Rice codes, and a data partitioning technique. HDCM with the aid of the proposed data partitioning enables the reconstruction of context modeling in the backward decoding, and further the complete backward decoding of CRVLC is possible. The proposed data partitioning also improves error resiliency. The experimental results show that on the test videos CRVLC has average 4.21% bit-rate savings and maximal 2.49dB error resilience improvement compared to 2D-RVLC.

Fourth, it is a valuable discussion on how to design an optimal context-based adaptive variable length coding technique for video DCT blocks

and what the maximally achievable coding efficiency is. This paper designs an context-based adaptive variable length coding technique, CBAVLC, aiming to maximize the achievable coding efficiency under acceptable complexity of practical video applications. CBAVLC uses HDCM. Its modeling performance can be viewed to be near optimal through our analysis. CBAVLC uses adaptive coding technique which can on-line estimate the probability distribution on each context in each time instance, and then selects optimal Golomb codes for coding. So the coding in CBAVLC is also near optimal. The experimental results show that CBAVLC has a little coding efficiency improvement than CAVLC. It indicates that CAVLC, C2DVLC, and HDCMVLC have been close to the highest coding efficiency obtainable under acceptable complexity in practical video applications.

Keywords: video coding, entropy coding, variable length coding, context modeling