Novel YUV 8bpp subsampling pattern

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***Abstract*— we propose a novel 8bpp subsampling YUV pattern based on a checkerboard subsampling of the luminance component that explicitly preserves the edge. The proposed pattern uses 1bit to encode edge direction in the missing luminance pixel and this bit is stored in the chroma sample as the chroma sample is DPCM encoded 8 to 7bits per sample. The complexity analysis of both encoder and decoder is concluded with a proposed hardware implementation. The image quality performance of the proposed pattern is estimated using MTF measurements, quantifying the loss in high-frequencies and a comparison is presented across the YUV subsampling methods.**

***Index Terms*—YUV, DPCM, RAW, Bayer.**

I. Introduction

YUV color coding (commonly used to refer to Y'CrCb) is widely used in uncompressed [1],[2],[3],[4] as well as in compressed [5],[6],[7] image data transmission due to the fact that it takes into account human perception. YUV encodes a color image into luminance and chrominance information allowing a more efficient masking of errors or some bandwidth reduction than the 'direct' RGB color representation. We note that our proposed solution can be applied to any variation of the YUV color coding, and because of this we do not detail further those variations.

Over the time, several ways of reducing data bandwidth for uncompressed YUV data were developed, offering 'visually lossless' quality. In this range of YUV arrangements, the full uncompressed YUV uses one sampling per color (for simplicity we use 8bit/color) making the full YUV data stream to be 24bits per pixel, usually denoted as YUV444 data format its spatial arrangement shown in Fig.1.(a).

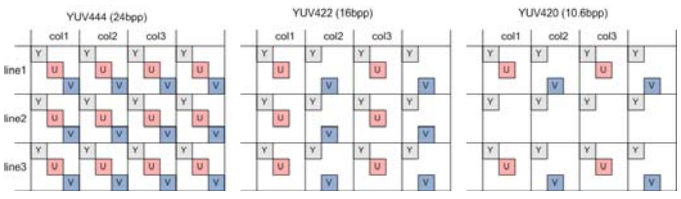


Fig.1 YUV color sampling formats spatial arrangement: (a) YUV444; (b) YUV422; (c)YUV420.

Further, a first step in data reduction is by subsampling chrominance by 2, considering the reduced color sensitivity of human eye, resulting in YUV422 – Fig.1.(b)- which requires 16bits per pixel to transmit a color image. Next, the chroma information can be subsampled even more with very little loss in perceived color resolution and this data format is known as YUV420 – Fig.1.(c)- and is used today as the basis of most compression schemes. YUV420 is not symmetric in representation due to vertical chroma subsampling, making it not friendly to data transmission. Even so, YUV420 achieves an average of 10.6bpp data compression with 'visually lossless' performance.

We propose a symmetric data transmission format that achieves 8bpp with comparable quality with YUV420. The proposed format subsamples the luminance plane is a checkerboard pattern – using Bayer's [11] type of sampling

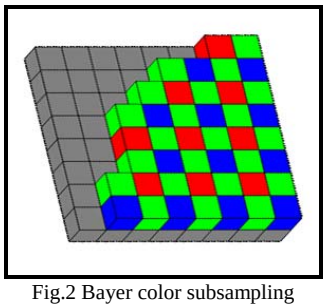


Fig.2 Bayer color subsampling

shown in Fig.2, which is widely used today in color image sensors. As one of the drawbacks of checkerboard sampling is a loss of frequency content and introduction of artifacts, we propose to include the edge orientation for each subsampled luminance pixel in data transmitted. To accomplish this, we compress further the chrominance from 8bit per pixel to 7bit per pixel, using a variant of DPCM compression which is widely adopted in image transmission for its 'visually lossless' quality (SMIA/MIPI standards for camera interfaces [8], [9]) and include the luminance edge information in the chroma sample. The resulting data format requires only 8bits of information per pixel and by rearranging the chroma samples in YUV420 pattern, we achieve a symmetric data transmission format for image data with 'visually lossless' quality. Further, we analyze the complexity and requirements of a hardware compression / decompression implementation. The implementation requires one line buffer and a simple DPCM compressor / decompressor to achieve 8/7 compression / decompression.

To evaluate the image quality degradation of the proposed scheme, we use traditional MTF methods used for cameras, as we expect a degradation of the frequency response. In addition, in a similar way, we examine artificial 'chromatic aberrations' introduced by this method as well as frequency response degradation for color components.

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We conclude our work by presenting a comparison between frequency degradation due to subsampling in all YUV formats and confirming with visual examples.

II. Fundamentals

Content originating from a camera is suitable to YUV subsampling in a perceptually lossless mode due to the fact that of the most of the color sensors in the market use BAYER sampling pattern [11], so both the luminance plane and the color plane are sparse already. YUV subsampling in current variants (YUV444, YUV422, YUV420) is potentially increasing the data bandwith of the original sensor information, in the case of RAW, Bayer sampled data, which is 8bit/pixel (in cases where the input RAW data has more bits e.g. 10bits or 12bits, usually DPCM compression is used to reduce it to 8bit or lower values [8], [9]). Therefore, ideally, there's need for a YUV format that goes to 8bpp, as it's convenient in terms of memory allocation and transfer bandwidth – in the above conditions (Bayer color filtering and DPCM compression to 8bit or less), this should not result in loss of information.

In those lines, our proposed solution used two known 'perceptual lossless' techniques in image data processing:

1. BAYER subsampling pattern [11] (used in most color image sensors on the market today)
2. DPCM data compression (as described in [10] is used in at least 2 standards for bandwidth reduction in cameras - SMIA and MIPI [8], [9])

Our solution combines those techniques and applies the resultant solution to a YUV pattern, achieving 8bit per pixel data compression. We apply Bayer sampling to the Y luminance plane. The usage of the Bayer sampling pattern relies on edge reconstruction; therefore, we include this information to allow for correct edge reconstruction. In our implementation we considered two alternatives to edge encoding:

a. Encoding only horizontal and vertical edges shown in Fig. 3 (a) and (b). H = 0, V = 1.
b. Encoding horizontal, vertical and two diagonal edges as shown in Fig. 4 (a), (b), (c) and (d). H = 00, V = 01, D1 = 10, D2 = 11.

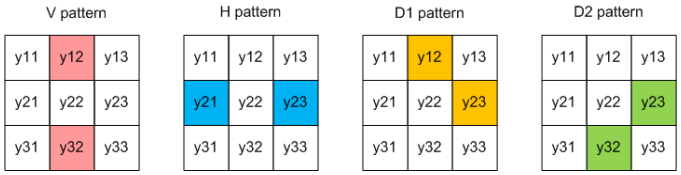


Fig.3. Edges encoded: (a) Vertical, (b) Horizontal, (c) Diagonal 1 (d) Diagonal 2

This proposal, uses the BAYER sampling pattern but applied to luminance, also it stores the edge orientation using 1-2 extra bits for each luminance missing sample.

To provide the extra bits needed to encode the luminance edge, the chrominance samples are DPCM compressed.

Each chrominance sample is compressed using 8to7 or 8to6 DPCM compression depending on how many bits are used to compress the edge information as shown in Fig3. In IV we analyze the resulting encoding and compare the two proposed solutions (using two encoded edges vs. four encoded edges).

Currently, DPCM 8to7 and 8to6 are not currently part of any DPCM compression mode, but this proposal follows the mechanism other DPCM compression modes are implementing [8], [9] (ie. 10to8, 10to7, 10to6, 12to8, etc…). This mechanism is illustrated for reference purposes in Fig. 4, as explained in [10] and adopted in [8] and [9].

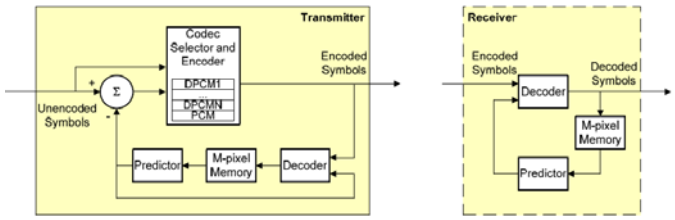


Fig.4. Standard DPCM compression: Left - Encoder; Right - Decoder

III. Implementation

Our implementation of the proposed solution requires minimal computations on both encoder and decoder, however, it needs two line buffers on the encoding side and one full line buffer on the decoding side (on decoding side, the luminance plane is sparse already, so two luminance lines amounts to one full image line).

When encoded, the pattern spatial arrangement is represented in Fig.5:

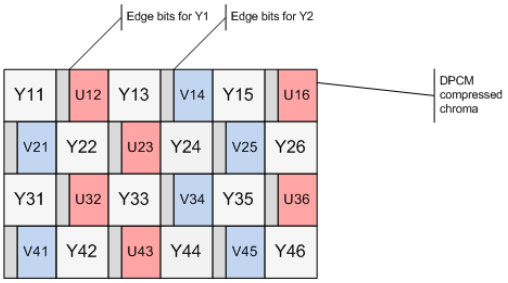


Fig.5 SYUV – Edge encoded spatial arrangement of proposed 8bpp YUV sampling

In the arrangement presented in Fig.5, the chroma positioning reflects the transmission arrangement to preserve a constant bandwidth (as opposed to YUV420, which is asymmetric in that regard), not necessarily spatial positioning of the chroma samples in the image space.

If this luminance subsampling pattern is applied to the common used YUV formats shown in Fig.1, new the YUV sampling rates obtained are:

YUV444 (24bpp) -> SYUV444 (20bpp), reduction of 16%

YUV422 (16bpp) -> SYUV422 (10.6bpp), reduction of 33%

YUV420 (10.6bpp) -> SYUV420 (8bpp), reduction of 25% of both datarate/bandwidth and ,memory requirement.

The resultant pattern arrangements are shown in Fig.6 (corresponding to Fig.1)

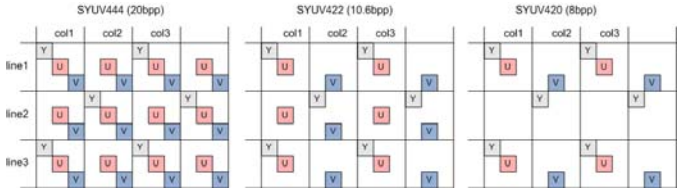


Fig.6. SYUV corresponding color sampling formats spatial arrangement: (a) SYUV444; (b) SYUV422; (c) SYUV420.

A block diagram of a proposed implementation of a compressor block is illustrated in Fig.7.

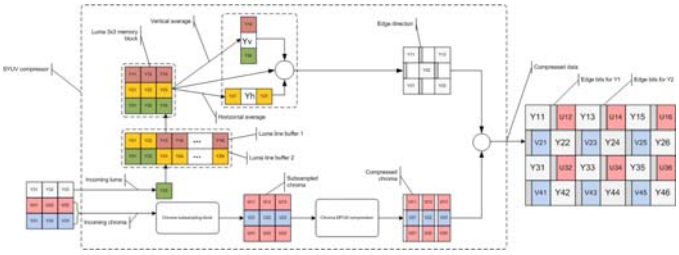


Fig.7. Proposed solution – Compression algorithm block diagram

For each luminance pixel, both horizontal and vertical gradients are compared, and the result will be encoded (if four edges are used, the other two gradients, as illustrated in Fig. 3, are calculated and the highest is encoded). Chrominance samples follow a different path and are encoded using DPCM 8to7 or 8to6, depending on the chosen number of encoded edges. On the decoding side, the edge is read out of the chroma samples (in our implementation, we used MSB to store the edge, but this is by choice) and the luminance missing sample is replaced by the appropriate average of the corresponding pattern pixels. We remark here that both encoding and decoding are very simple to implement.

IV. Evaluation Results

To evaluate our proposed solution, we used the degradation of MTF of a compressed-decompressed image using our algorithm and compared it with its corresponding source YUV pattern.

We decided to look at MTF degradation, since we know that subsampling the luminance is affecting the edge. Also, we used chromatic aberrations indications to evaluate the presence of artifacts in chroma samples. For the complexity of DPCM implications on edge degradation and measured MTF we refer to [12]. In our evaluations we used a commercial product to quantify both MTF and chromatic aberrations [13].

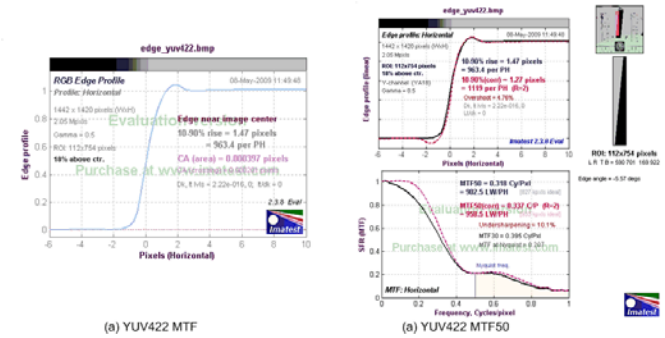


Fig.8. YUV422 MTF and MTF50 (Nikon D3x)

For our measurements we used pictures taken with a Nikon D3x, showing good MTF characteristics (Fig. 8).

Our results for each edge type of encoding are presented in Fig.9:

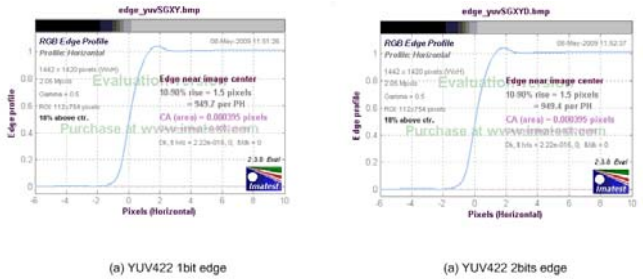


Fig.9. YUV422 edge encoding performance: (a) 1 bit edge; (b) 2 bits edge

We notice here that the 2bit edge encoding doesn't justify the extra bit used for encoding.

V. Conclusion

We presented a solution to allow encoding and transport of a YUV data applicable to all YUV data formats (YUV444, YUV422 and YUV420) that achieves between 16% and 33% efficiency over the original YUV format, is 'visually lossless' and offers an alternative to YUV420, further reducing this format to 8bpp, with uniform datarate. We discussed an implementation of a compressor and decompressor for this solution, noting the computational simplicity required. To evaluate performance, we compared our implementation with uncompressed original format and estimated the MTF degradation due to edge encoding/decoding and introduction of chroma artifacts through use of chromatic aberrations.

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