9-3: Multi-Valued Image Entropy Coding for input-width reduction of LCD source drivers

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Abstract

A new joint source channel coding reduces both input-width and average current consumption to transmit image data to LCD source drivers. As a source coding, it is based on entropy coding of differential pulse code modulation scheme, especially using median edge detector of image predictor. As a channel coding, it is not a simple pulse amplitude modulation, but linked by source entropy to reduce average amplitude. Simulation results show 1/4 width is achievable by 16-valued transmission with keeping conventional current consumption (0.36 to 1.3).

1. Introduction

The rapid increase of image size recently addressed not only the EMI problem but also input-width problem. The latter problem is concerned to promote further cost reduction towards PCB-less and advanced COG for LC-TV and monitor. Especially for mobile phone, thick bundle of wire through hinge (mechanical connection parts of upper display and lower body) should be improved to thin in order to realize mechanical flexibility. For these problems, many data transmission proposals are rushing: mini-LVDS (Low voltage differential signaling), RSDS (Reduced swing differential signaling), CMADS (Current mode advanced differential signaling), whisper BUS, and further more proposals targeted to mobile applications: mobile-CMADS, MSDL (Mobile Shrink Data Link), MVI (Mobile Video Interface), MPL (Mobile Pixel Link). These proposals based on current-mode transmission seem to successfully solve the problem, but it is interim by expecting further massive increase of image and limit of circuit improvements. Therefore another add-on approach based on different principle is desired.

To reduce input-width, following three kinds of approaches seem feasible: (1) faster data transmission rate, (2) data compression, and (3) multi-valued transmission. Firstly, as data transmission rate of source driver is nearly 200 MHz, and further speed-up causes extra-penalty concerning signal synchronization and transmission-line matching, which imposes circuit cost larger and larger. This also causes both IC and PCB cost larger. Such extra cost are not preferable, especially for near-GHz operation. As a second way, JPEG archived high-compression rate and hopefully expected to reduce width. However, its DCT circuit is too large to include it in source driver. Another JPEG approach known as JPEG-LS (lossless) retains its circuit size small, however, its compression rate is relatively poor, not to achieve 1/2 constantly. Its compression rate is heavily dependent on image itself, and therefore, data are not transferred fully in a worst case. EMI suppression is similar to data compression, however it is not directly applicable to data compression. As a third way about MVL (multi-valued logic) transmission, ternary or quaternary valued transmissions are practically popular. Increase of level is serious for practical application by considering power consumption. In addition, ADC (analog to digital converter) has minimum current to keep operation speed high, so reduction of unit current is also physically restricted. Thus practical applications are limited to ternary or quaternary.

Our novel approach not only reduces the input-width but also suppresses such increase of current consumption caused by MVL- transmission. It is based on the statistical property of images. Our entropy coding has the same background exploited by JPEG-LS Golomb code, however its exploitation is quite different. Golomb code tries to reduce code-length to compress data. On the other hand, our approach tries to reduce the average current amplitude of MVL code.

2. Multi-Valued Image Entropy Coding

Figure 1 shows the signal flow of our system. Figure 2 (2a and 2b) shows the pre-processing for CD (color difference) signals and MED (Median Edge Detector). Image data is pre-processed first by generating CD signals in order to improve correlation more sharp: RGB data are converted into R-G, B-G, and G. Despite the fact that YCrCb is preferable for human visual perception, here we choose intentionally RGB color difference signals because RGB is easy to implement smaller hardware. Next step is a DPCM (Differential Pulse Code Modulation) based on MED predictor. As DPCM is a general scheme, predictor is not limited to MED, and other predictors like GAP (Gradient-Adjusted Predictor) are also exploitable.

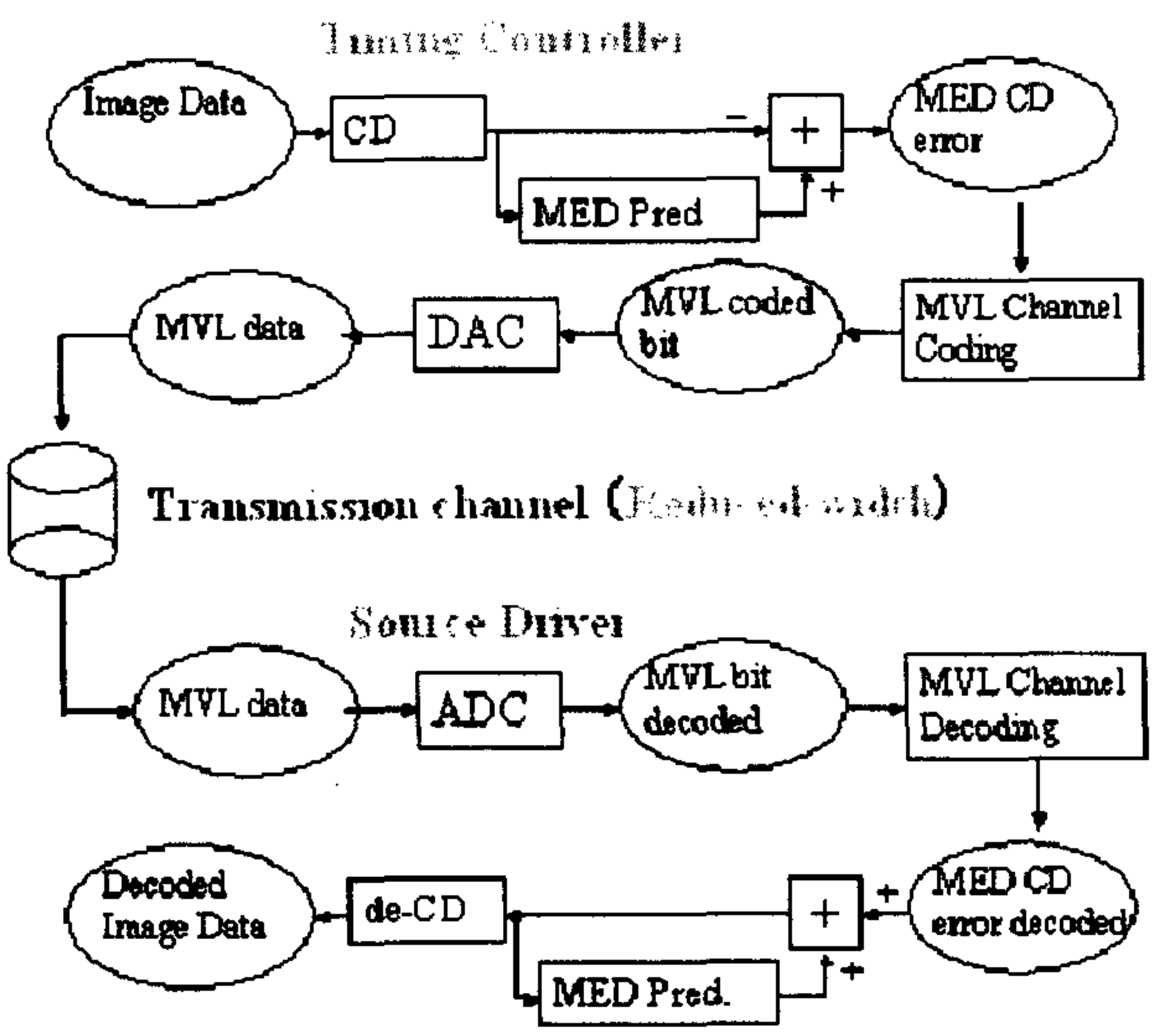

Figure 1. Signal Flow of MVIEC

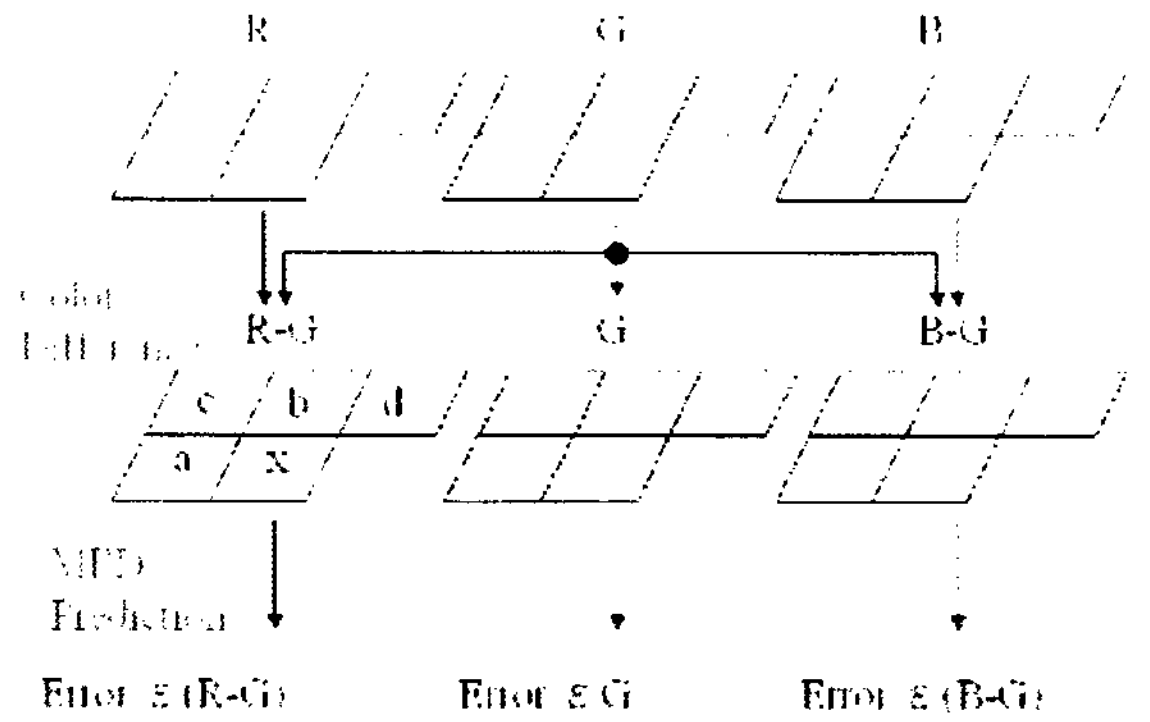

Figure 2a. Processing of Color Difference (CD) and MED.

```
if (c ≥ max (a, b))
  { if ((c - max (a, b)) > T1 AND (abs (a - b) ≤ T2 )
      x̂ = b + d - a;
    else
      x̂ = min (a, b);
  }
if (c ≤ min (a, b))
  { if ((min (a, b) - c) > T1 AND (abs (a - b) ≤ T2 ))
      x̂ = b + d - a;
    else
      x̂ = max (a, b);
  }
else
      x̂ = a + b - c;
endif
```

Figure 2b: Edirisinghe MED predictor.

Figure 2. The MED (Median Edge Detector) described here is adopted from [1]. The pixel positions are marked by a, b, c and d around the current position x (see Figure 2a) and are intentionally overload its meaning as values for their positions. For instance, the position of "a" is a horizontally previous pixel of the current pixel "x". The position "b" is a vertically previous pixel of the current pixel "x". So, 1H line memory is required for the MED prediction. Predicted value is marked by hat like $\hat{x}$. The first prediction formula $\hat{x} = b + d - a$ is the case of detecting diagonal edge. The second prediction formula $\hat{x} = \min(a, b)$ and third formula $\hat{x} = \max(a, b)$ are the cases of detecting horizontal or vertical edges. The last formula $\hat{x} = a + b - c$ is the case of flat plane. The parameters T1 and T2 select such cases by considering the edge. Then the residual error is the difference of the current value of x and the predicted value $\hat{x}$. That is the error is given by $\varepsilon = \hat{x} - x$. Actually, there are three errors according to R-G, G, and B-G signals.

Error ε	Δ0	Δ1	Δ2	Δ3	Δ4	Δ5	Δ6	Δ7	Prob p(ε)
0	0	0	0	0	0	0	0	0	p(0)
1	1	0	0	0	0	0	0	0	p(1)
-1	0	1	0	0	0	0	0	0	p(-1)
2	1	1	0	0	0	0	0	0	p(2)
-2	0	0	1	0	0	0	0	0	p(-2)
3	1	0	1	0	0	0	0	0	p(3)
-3	0	1	1	0	0	0	0	0	p(-3)
4	1	1	1	0	0	0	0	0	p(4)

Figure 3. Channel code bit generator: Each code has 8-bit depth. For instance, MSB of Δ(R-G) is represented as Δ(R-G)7. The probability p(ε) is approximated by an extended Laplace distribution (two sided geometrical distribution). Different from Golomb code, our code has same bit-length and is mapped further by the MVL-mapping defined by Figure 4. This table is valid for (R-G), (B-G) and G signals.

①= ΔG0 + 2*Δ(B-G)3 + 4*Δ(R-G)3 + 8*Δ(R-G)7

② = ΔG1 + 2*ΔG4 + 4*ΔG5 + 8*Δ(B-G)7

③= ΔG2 + 2*Δ(R-G)2 + 4*Δ(B-G)4 + 8*Δ(R-G)6

④= Δ(B-G)0 + 2*Δ(B-G)2 + 4*Δ(R-G)4 + 8*Δ(B-G)6

⑤= Δ(R-G)0 + 2*ΔG3 + 4*ΔG6 + 8*Δ(R-G)5

⑥= Δ(B-G)0 + 2*Δ(R-G)1 + 4*ΔG7 + 8*Δ(B-G)5

Figure 4. MVL-mappings: Assign lower probability bit first as MSB in order to minimize average current. As the average of current is given by the sum of these six expressions, the swap of 16-valued code in the same bit position (for example, Δ(R-G)7 and Δ(B-G)5) causes no change in the average. This means our mapping is robust in swapping when we try to configure such MVL-mapping. In a conventional MVL, all bits have equal probability 0.5. Therefore, each value of MVL mapping has 7.5 as an average current value. On the contrary in our case, an average current value is reduced as described in Figure 6.

The residual error between prediction and actual is transmitted as data. In a receiver (LCD source driver), the residual error is added to the prediction generated by another instance of predictor in order to decode it. Here, we use the Edirisinghe 's MED [1] as one of most powerful MED. Then, the residual error is coded into multi-valued code on the channel, the input bus to source drivers. On the channel, current amplitude is statistically very reduced by our proposal. This is the essence of our paper. Figure 3 and Figure 4 give a mapping to realize such a multi-valued channel coding. Figure 3 is the first step, which generates coded bits from the residual error. Figure 4 is the second step, which assigns the MVL-values for coded bit by the "transmission data protocol" based on the MVL-mapping. Thus, PAM (pulse amplitude modulation) is completed. The essential advantage comes from the formulation of MVL-mapping itself in how to exploit image entropy. The length of Golomb code is not reduced well compared to the value of MVL-mappings because the probability causes exponential reduction in MVL-mapping (weighted by the power of 2), however reduction ratio of length is saturated at near zero residuals for Golomb code. Thus, Golomb code cannot fully exploit high-correlation. Furthermore, MVL-mapping has tolerance in reducing wire width. In the case of Golomb code, poor correlation cannot achieve 1/2 compression ratio, that means half width reduction of wire cannot transmit all of data. On the other hand, MVL-mapping may generate high current value instantly, but all of data are transferred. When image correlation goes well, its current also returns small. Golomb code approach is heavily restricted by worst cases. It is a fatal disadvantage.

Let's apply our technology to CMADS [2] for instance: input-width is reduced to 1/4 (12 lines to 3 lines), and simultaneously its current is reduced well (Table 1). We propose the MVL-mapping (Figure 4) expressed by mapping four bits to single 16-valued code. The set of six such mappings

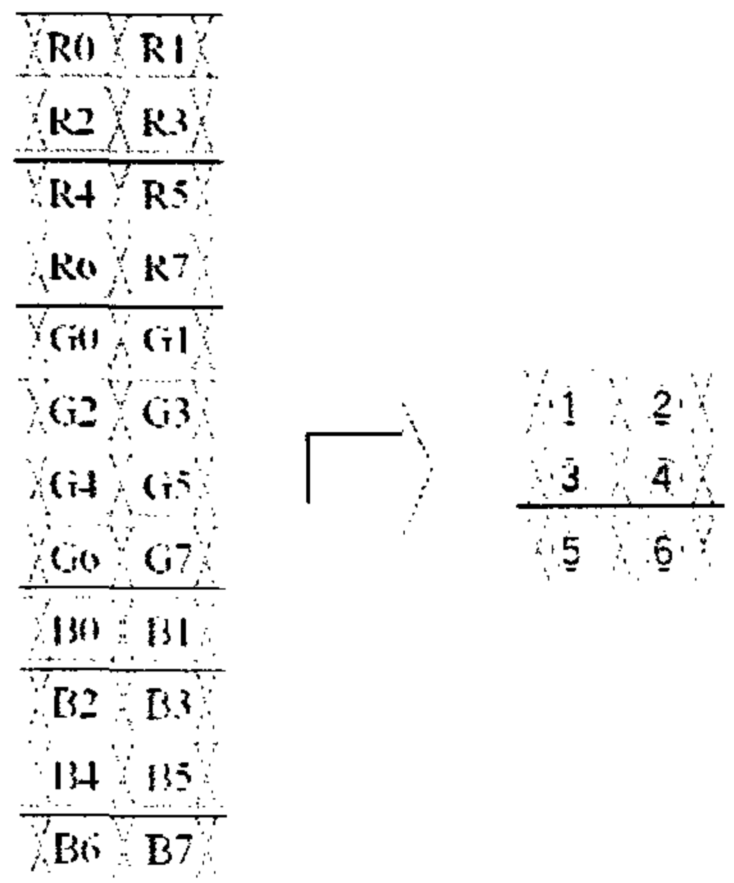

Figure 5. Width Reduction of transmission: The RGB original data (left hand side) may have another configuration, and the proposed 16-valued data (right hand side) also may have another configuration. Each right 16-valued slot is defined by the MVL-mapping shown in Figure 4. As width-reduction is 12 to 3, four lines of binary original RGB transfer is reduced to single line of 16-valued transfer, so that these four lines are summed (2 units current = 8mA) in order to compare with single 16-valued line as shown in Figure 6. Another possible extension is the insertion of extra slots to transfer extra bits such as control of trigger to sleep mode, or data bits of gamma voltage setting.

transforms 24 bits (RGB one pixel) into six 16-valued code on 3 lines during two periods (Figure 5). Figure 6 compares the estimated current consumption per 16-valued line. The companion paper [4] will describe the details. As there is a trade-off between input-width and current consumption, we don't adhere the 16-valued MVL-mapping described here. Another 4-valued mapping reduced the width by 1/2, however its average current is smaller than 1: roughly speaking 1/2 or smaller. You can choose such a 4-valued mapping based on our coding principle. If you could improve circuit directly to implement 4-valued logic circuit with keep swing current equal (that is unit current is reduced to 1/4) for example, further high-valued like 64-valued mapping may be implemented.

3. Discussion

All of current interface proposals such as CMADS are based on circuit improvements. Our approach is based on the completely different principle: entropy coding, and therefore is generally compatible with these proposals to add-on. We recommend all interface standards to adopt our principle. MVI (Mobile Video Interface) adopts 8b10b coding as channel coding, so it is an exception (not compatible with our principle). MVI has clock line as independent line. Additionally PLL circuit is removed

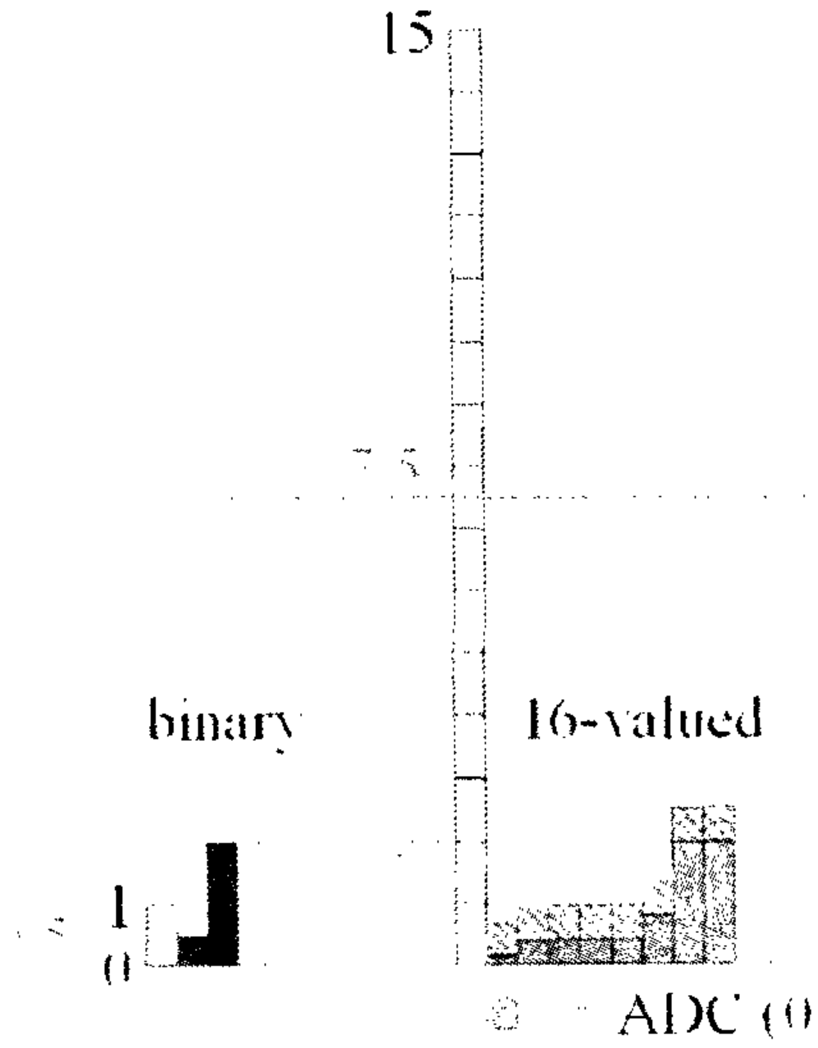

Figure 6. Current Estimation. The histogram for single line of 16-valued code is calculated by the MATLAB analyses on the image data sets: "pc", "science fiction", "amine", "national park", "mystery", "master piece", "America" and "sakura" from left to right. ADC decodes received 16-valued signal. ADC has total 2mA as reference current. It is prerequisite to nearly 200 MHz operation speed. The sum of these reference currents is principal factor of current consumption. Data current reduced after receiving amp is 1/10 by our entropy coding. Finally, we add the estimated 2.2mA per ADC, which are equivalently 0.55 units current. Two right-most image data sets ("America" and "sakura") are over the equivalent-binary current consumptions. Others are lower than it.

because its removal is more effective to reduce power consumption than clock line removal. It seems redundant for us that removal of PLL still requires 8b10b channel coding. Recently proposed Point-to-Point scheme [9,10] are also compatible with our MVIEC.

The MVIEC is considered as an extension of the Okumura's pioneering work [3] that exploits image entropy for EMI reduction. It is based on 1H-differentiation and binary transmission. Our coding is proposed in more general context by DPCM and MVL, and our target is width reduction. The replacement of 1H-differentiation by any other powerful predictor like MVIEC is possible in the Okumura's work in order to achieve more EMI suppression.

Cheng proposed another pioneering entropy coding [5]. It is the modified TMDS (Transition Minimized Differential Signaling) by sorting code words according to their transition counts. It is targeted for DVI, and is based on binary transmission, the chromatic coding and the simple spatial predictor: 1V-differentiation. Its circuit cost (especially for analog part: signal-receiving amplifier and PLL circuit) is large because of the DVI request of long cable drivability, so it is not preferable for source drivers. Our cable length is short, and PLL circuit is intentionally removed to keep small size. TMDS coding controls disparity within certain range to assure PLL synchronization. The static sorting of code word may disturb such disparity control provided by the original TMDS policy: the dynamic choice of code word by the current status of disparity. This concern may be resolved by the global symmetric property of the error distribution, but not verified yet. It is a future problem to be discussed. Anyway, the difference between Cheng approach and ours comes from the target of transmission, so that naive careless comparison is danger. However, their chromatic coding is attractive to improve our simple color-difference coding.

Massive image transfer is becoming popular and more urgent for not only display drivers but also other devices such as image sensor, image memory, and image processor. DCT circuit used in data compression is too large and not preferable to be included in peripheral drivers. Our coding is best for such devices. Aizawa [6] proposed intelligent sensor that compress the data by selective transmission: only when 1-frame previous pixel value is not equal to the current pixel value, then transmit current data. The situation is exactly same as transmission of LCD source drivers.

set name	Average current	# of images	Size and format
pc	8.8 mA (36%)	14	1280x1024 bmp (screen dump)
science fiction	11.6 mA (48%)	25	720x480 bmp (DVD MPEG2)
anime	12.0 mA (50%)	52	720x480 bmp (DVD MPEG2)
national park	13.4 mA (56%)	75	720x480 bmp (DVD MPEG2)
mystery	12.[illegible] mA (5[illegible]%)	30	720x480 bmp (DVD MPEG2)
master piece	16.3 mA (68%)	32	various size 417x563 average, JPEG (from TNM web)
America	30.4 mA (127%)	100	640x480 TIFF (CDROM photo)
sakura	31.2 mA (130%)	72	640x480 JPEG (CDROM photo)

Table 1. The table of image sets. The average value of current is the total, the sum for three lines. The percent attached is measured by the conventional current consumption 24mA = 12 lines * 4mA * 0.5. Note that DVD MPEG2 images are 4:2:0 sub-sampled implicitly, and this processing improves their images correlations. See details in the companion paper [4].

As a MVL, our 16-valued transmission (16-PAM) is the first drastic achievement of high MVL as low current cost as conventional low MVL (ternary or quaternary). For instance, Kim [7] discussed TMDS modification that 3 or 4-valued logic is easy to implement, but 8-valued transmission requires further optimization of circuit. They couldn't mention about 16-valued transmission because of difficulty. As today's most aggressive PAM, even IEEE 802.3an (10Gb Ethernet) [8] has 8-PAM, 10-PAM and 12-PAM as mainstream proposals. They are different from MVIEC because they are not joint source channel coding, and therefore they cannot reduce average power consumptions further.

4. Conclusion

A new joint source channel coding is proposed based on DPCM scheme with MED predictor and MVL. The MVL-mapping joint two factors: source coding by MED and channel coding by MVL. This linkage reduces both width (to 1/4) and average current amplitude (0.36 to 1.3) of interface for LCD source drivers.

5. References

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