SHARP

Application Note

LCD Color Palette Generation

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INTRODUCTION

One of the important considerations in selecting a display for an application is meeting the application's requirements concerning the number of gray scale shades or color shades that need to be displayed. What 'must' be displayed is determined by the application. What 'can' be displayed is determined by several system factors including the display itself, the display controller, and other system architectural factors.

In this application note, only LCD displays are discussed. The techniques for palette extension discussed are relevant to other display types (CRT, EL, etc.) taking into consideration the properties of these displays (speed, maximum contrast ratio, etc.).

APPLICATION REQUIREMENTS

How many gray scale shades or color shades are needed for a particular application? That depends on the type of information being displayed. The fundamental question is how much or how little contrast change is needed between data elements.

Text

Text is the simplest application example. What is desired is high contrast between the text and background. Black and white are the usual choice. Sometimes, two high contrast (complementary) colors are chosen. For text processing applications it is quite often desirable to have one or two additional shades for the purposes of highlighting text for selection or emphasis.

Simple Graphics

For simple geometric graphic applications, the goal is to have enough shades to easily differentiate several types of objects. In typical CAD applications, this number is usually between 6-12. Shades are normally selected to provide the highest contrast between object types.

2D and 3D Surface Shading

In more sophisticated CAD applications and synthesized multimedia images involving rendering of two-dimensional and three-dimensional surfaces (where variations in gray scale or color shade represent variations in lighting intensity or properties such as density), it is desirable to have a sufficient number of shades so that the contrast between two adjacent shades is barely distinguishable. This minimizes the banding lines which are a distraction in viewing 'smooth' surface renderings.

The number of gray shades required to achieve smooth shading is somewhat dependent on the display used. The more contrast the display has, the more shades needed. It is also a somewhat subjective criteria. The perceptible improvement decreases exponentially with the number of shades. In general, somewhere between 64 and 256 shades will be sufficient for smooth shading.

Color shade requirements follow the same rules as gray scale shading, except that there are three primary colors (which can be thought of as sets of 'gray shades'). The combination of these produces a fairly large set of color shades. For smooth surface rendering it is generally agreed that between 256K (64^3) and 16M (256^3) shades are sufficient. Again, this is dependent on the application's subjective factors and the performance of the display. For high-end scientific and medical applications using very high quality displays, 16M shades is the normal specification requirement.

Video

Video has fundamentally the same requirements as smooth surface rendering. Shade limitations that result in banding or blotchiness can be very noticeable and are probably most pronounced in facial features.

NATIVE LCD CAPABILITIES

The native capability of the display refers to how many shades can be displayed in a 'static, all pixels at the same intensity' mode. This means that no controller generated shade palette extension techniques are used.

Passive Monochrome

Passive monochrome displays produce two native shades, namely black and white. In static mode, the pixels are either on or off. Pixel switching time for typical VGA panels is around 150 ns to 250 ns. Typical contrast ratios are between 20:1 to 30:1. Normally, the number of distinguishable gray shades is between 32 and 64.

Passive Color

Passive color displays produce eight native shades which represent the possible combinations for each primary being on or off. Again, in a static mode, the R, G, or B sub-pixels are either on or off. Pixel switching times and contrast ratios are similar to passive monochrome VGA panels. The number of distinguishable color shades is typically between 32K (32^3) and 256K (64^3).

Active (TFT) Color

Active color displays usually have multiple static shades per R, G, or B sub-pixel. In static mode, the pixels are either on or off. Pixel switching time for typical VGA panels is about 50 ns. Typical contrast ratio is around 60:1. The number of distinguishable color shades can be greater than 256K (64^3).

CONTROL TECHNIQUES FOR COLOR PALETTE EXTENSION

For the purposes of this section, the discussion will focus on color shade generation with the understanding that the same techniques and trade-offs apply to gray scale generation also.

Spatial

Halftoning

Halftoning refers to modulating pixel size to control shading. It has traditionally been used in the printing industry. Since the pixel size of an LCD display is fixed, this approach is not feasible and, therefore, not used.

Dithering

Dithering is a means of producing color shades by controlling the relative number of on vs. off pixels in a small defined group. The larger the number of pixels in the group, the larger number of possible shades that can be produced. Dithering has the advantage over temporal techniques with regard to flicker problems and to driver bandwidth issues. It can be used effectively for both faster response (active) and slower response (passive) displays. The main limitation with dithering is that as the pixel group size gets larger, spatial noise or graininess increases. Normally, a small pixel group is used, typically 2×2. For certain applications, a larger group size, 4×4 or even 8×8 might be used, but certain shades may be very grainy, and therefore, maskedout of the users palette set.

Example

- 3-bit per primary (8 shades per subpixel) display.
- Dithering to add 2-bit additional shade levels (21 shades, interspersed 3 in a group, between original 8). Per primary result is 29 shades.
- Result is $29 \times 29 \times 29 = 24{,}389$ color shades.

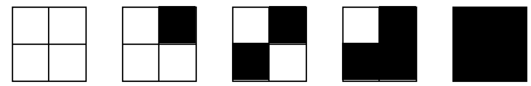

Figure 1. Dithering Spatial Shade Generation Technique

Temporal

Pulse Width Modulation (PWM)

Pulse width modulation controls the actual pixel drive time (drive pulse width) during the pixel's select time (on a passive LCD, this is normally one 'line' select time). The main difficulty in implementing this is that the fine resolution time control involved would require clock signals pushed into the hundreds of megahertz range. This is not practical, and the PWM technique is not used in typical applications. PWM also causes severe crosstalk on passive LCDs.

Frame Rate Modulation (FRM)

Frame rate modulation (also referred to as frame rate duty cycle and intermodulation) is a technique of modulating a pixel's on vs. off time over multiple frames. The advantage of this technique is that it does not have the spatial graininess of the dithering technique. It does have its own limitations, though. The more shade levels synthesized by frame rate modulation, the longer the modulation period (in terms of number of frames). When the modulation period approaches the response time of the display, distracting visual effects start becoming visible. 'Flicker' is the apparent 'pulsing' or 'beating' of a particular shade. Another effect that may be detected is perception of moving or 'rolling' of a shade. Both of these effects can be accentuated by ambient fluorescent lighting.

This technique works better with passive displays than with active displays because they are slower and will 'average out' the visual effects of switching the pixels on and off rapidly. With active displays, use of frame rate modulation is more limited because of flicker and motion effects. Essentially, with fast displays, use of FRM should be kept to a minimum level.

The actual modulation of the pixels can be implemented in a couple of schemes. All pixels of a particular shade can be turned on and off simultaneously, but this can cause significant flickering. The normal scheme involves taking subgroups of the pixels and alternating between them. Every other line or line segment in an area for a scheme that adds one level of shading (essentially doubling the number of shades) is a simple example. As more synthesized shades are added, the number of subpixel groups increase, and the modulation period gets longer, motion effects start to appear. Using more 'visually random' subgroups will help cut down this effect to some degree.

Example:

- 3-bit per primary (8 shades per subpixel) display.
- FRM to add 1-bit additional shade level (7 shades interspersed between the original 8). Per primary result is 15 shades.
- Result is 15 × 15 × 15 = 3375 color shades.

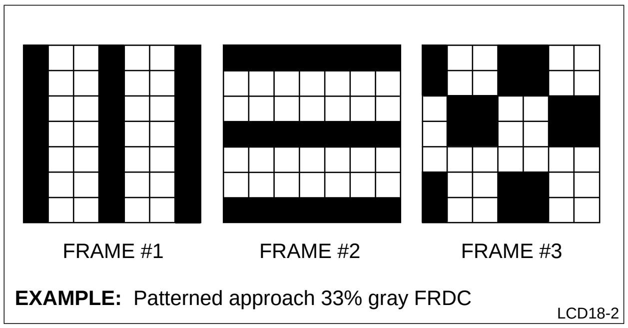

Figure 2. Frame Rate Modulation Eliminating Flicker

Combination of Techniques

For most applications, both dithering and frame rate modulation techniques can be combined to extend the color palette significantly without pushing either technique beyond its limits of reasonable performance. The idea is to allow each technique to add some number of 'bit per primary' capability to a display to achieve the applications requirements. An example would be a 4-bit per primary TFT display using dithering to add three bits additional capability and FRM to add one bit additional. This would achieve an 8-bit per primary capability, suitable for most rendering and multimedia applications. This could also be achieved by getting an 8-bit per primary TFT display. However the latter may not be the most cost effective (or even available) solution. (Refer to Tables 1, 2, and 3.)

Table 1. Monochrome Passive Palette

<table>
<tr><th rowspan="2">FRAME RATE MODULATION</th><th rowspan="2">EFFECTIVE DITHERING</th><th colspan="3">IMAGE</th></tr>
<tr><th>32 G.S. (5 BITS)</th><th>64 G.S. (6 BITS)</th><th>256 G.S. (8 BITS)</th></tr>
<tr><td>4 Frames (2 bits)</td><td>None</td><td colspan="3">4 (2^2)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">8 (2^3)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>2 × 2 Pattern (2 bits)</td><td colspan="3">16 (2^4)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>4 × 2 Pattern (3 bits)</td><td colspan="3">32 (2^5)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>4 × 4 Pattern (4 bits)</td><td rowspan="3">32 (2^5)</td><td colspan="2">64 (2^6)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>8 × 4 Pattern (5 bits)</td><td rowspan="2">64 (2^6)</td><td>128 (2^7)</td></tr>
<tr><td>4 Frames (2 bits)</td><td>8 × 8 Pattern (6 bits)</td><td>256 (2^8)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>None</td><td colspan="3">8 (2^3)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">16 (2^4)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>2 × 2 Pattern (2 bits)</td><td colspan="3">32 (2^5)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>4 × 2 Pattern (3 bits)</td><td rowspan="3">32 (2^5)</td><td colspan="2">64 (2^6)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>4 × 4 Pattern (4 bits)</td><td rowspan="2">64 (2^6)</td><td>128 (2^7)</td></tr>
<tr><td>8 Frames (3 bits)</td><td>4 × 8 Pattern (5 bits)</td><td>256 (2^8)</td></tr>
<tr><td>16 Frames (4 bits)</td><td>None</td><td colspan="3">16 (2^4)</td></tr>
<tr><td>16 Frames (4 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">32 (2^5)</td></tr>
<tr><td>16 Frames (4 bits)</td><td>2 × 2 Pattern (2 bits)</td><td rowspan="3">32 (2^5)</td><td colspan="2">64 (2^6)</td></tr>
<tr><td>16 Frames (4 bits)</td><td>4 × 2 Pattern (3 bits)</td><td rowspan="2">64 (2^6)</td><td>128 (2^7)</td></tr>
<tr><td>16 Frames (4 bits)</td><td>4 × 4 Pattern (4 bits)</td><td>256 (2^8)</td></tr>
</table>

Table 2. Color Passive Palette

<table>
<tr><th colspan="2">EACH PRIMARY COLOR RGB</th><th colspan="3">IMAGE</th></tr>
<tr><th>FRAME RATE MODULATION</th><th>EFFECTIVE DITHERING</th><th>32K COLORS (15 BITS)</th><th>256K COLORS (18 BITS)</th><th>16.8M COLORS (24 BITS)</th></tr>
<tr><td>4 Frames (2 bits)</td><td>None</td><td colspan="3">64 (2^{6})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">512 (2^{9})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>2 × 2 Pattern (2 bits)</td><td colspan="3">4K (2^{12})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>4 × 2 Pattern (3 bits)</td><td colspan="3">32K (2^{15})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>4 × 4 Pattern (4 bits)</td><td rowspan="3">32K (2^{15})</td><td colspan="2">256K (2^{18})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>8 × 4 Pattern (5 bits)</td><td rowspan="2">256K (2^{18})</td><td>2M (2^{21})</td></tr>
<tr><td>4 Frames (2 bits)</td><td>8 × 8 Pattern (6 bits)</td><td>16.8M (2^{24})</td></tr>
<tr><td>8 Frames (3 bits)</td><td>None</td><td colspan="3">512 (2^{9})</td></tr>
<tr><td>8 Frames (3 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">4K (2^{12})</td></tr>
<tr><td>8 Frames (3 bits)</td><td>2 × 2 Pattern (2 bits)</td><td colspan="3">32K (2^{15})</td></tr>
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<tr><td>8 Frames (3 bits)</td><td>4 × 4 Pattern (4 bits)</td><td rowspan="2">256K (2^{18})</td><td>2M (2^{21})</td></tr>
<tr><td>8 Frames (3 bits)</td><td>8 × 4 Pattern (5 bits)</td><td>16.8M (2^{24})</td></tr>
<tr><td>16 Frames (4 bits)</td><td>None</td><td colspan="3">4K (2^{12})</td></tr>
<tr><td>16 Frames (4 bits)</td><td>2 × 1 Pattern (1 bit)</td><td colspan="3">32K (2^{15})</td></tr>
<tr><td>16 Frames (4 bits)</td><td>2 × 2 Pattern (2 bits)</td><td rowspan="3">32K (2^{15})</td><td colspan="2">256K (2^{18})</td></tr>
<tr><td>16 Frames (4 bits)</td><td>4 × 2 Pattern (3 bits)</td><td rowspan="2">256K (2^{18})</td><td>2M (2^{21})</td></tr>
<tr><td>16 Frames (4 bits)</td><td>4 × 4 Pattern (4 bits)</td><td>16.8M (2^{24})</td></tr>
</table>

Table 3. TFT Palette

<table>
<tr><th colspan="2">EACH PRIMARY COLOR RGB</th><th colspan="3">IMAGE</th></tr>
<tr><th>GENERATED BY LCD</th><th>EFFECTIVE DITHERING</th><th>32K COLORS (15 BITS)</th><th>256K COLORS (18 BITS)</th><th>16.8M COLORS (24 BITS)</th></tr>
<tr><th colspan="5">512 COLOR TFT LCDs</th></tr>
<tr><td rowspan="7">3 bits</td><td>None</td><td colspan="3">512 (2^{9})</td></tr>
<tr><td>2 × 1 Pattern (1 bit)</td><td colspan="3">4K (2^{12})</td></tr>
<tr><td>2 × 2 Pattern (2 bits)</td><td rowspan="5">32K (2^{15})</td><td colspan="2">32K (2^{15})</td></tr>
<tr><td>4 × 2 Pattern (3 bits)</td><td rowspan="4">256K (2^{18})</td><td>256K (2^{18})</td></tr>
<tr><td>4 × 4 Pattern (4 bits)</td><td>2M (2^{21})</td></tr>
<tr><td>8 × 4 Pattern (5 bits)</td><td rowspan="2">16.8M (2^{24})</td></tr>
<tr><td>8 × 8 Pattern (6 bits)</td></tr>
<tr><th colspan="5">4K COLOR TFT LCDs</th></tr>
<tr><td rowspan="7">4 bits</td><td>None</td><td colspan="3">4K (2^{12})</td></tr>
<tr><td>2 × 1 Pattern (1 bit)</td><td colspan="3">32 K (2^{15})</td></tr>
<tr><td>2 × 2 Pattern (2 bits)</td><td rowspan="5">32K (2^{15})</td><td colspan="2">256K (2^{18})</td></tr>
<tr><td>4 × 2 Pattern (3 bits)</td><td rowspan="4">256K (2^{18})</td><td>2M (2^{21})</td></tr>
<tr><td>4 × 4 Pattern (4 bits)</td><td rowspan="3">16.8M (2^{24})</td></tr>
<tr><td>8 × 4 Pattern (5 bits)</td></tr>
<tr><td>8 × 8 Pattern (6 bits)</td></tr>
<tr><th colspan="5">256K COLOR TFT LCDs</th></tr>
<tr><td rowspan="7">6 bits</td><td>None</td><td rowspan="7">32K (2^{15})</td><td rowspan="7">256K (2^{18})</td><td>256K (2^{18})</td></tr>
<tr><td>2 × 1 Pattern (1 bit)</td><td>2M (2^{21})</td></tr>
<tr><td>2 × 2 Pattern (2 bits)</td><td rowspan="5">16.8M (2^{24})</td></tr>
<tr><td>4 × 2 Pattern (3 bits)</td></tr>
<tr><td>4 × 4 Pattern (4 bits)</td></tr>
<tr><td>8 × 4 Pattern (5 bits)</td></tr>
<tr><td>8 × 8 Pattern (6 bits)</td></tr>
</table>

SPECIFIC CONSIDERATIONS

VGA Compatibility

The VGA architecture definition imposes some limitations of its own in terms of both the number of color shades that can be and must be displayed. The current normal VGA mode used is 256 color shades in use from a palette of 256K color shades. If certain assumptions are made about the color palette selected, then a 3-bit per primary (512 colors) display could meet VGA requirements. The VGA spec, however, makes no particular restrictions, so that it would actually take a palette of 256K colors to meet the requirements in the general case. A limitation of the VGA spec is that without a mode to support more than 256 colors at one time, VGA itself presents a serious limitation for smooth surface rendering and life-like video.

Color Mapping to Gray Scale

Mapping color shades to gray scale shades has a variety of implications depending on the type of information being displayed. Transitioning to gray scale is fundamentally a loss of information.

For text and simple graphics, the objective is to map the colors to a set of gray shades that will provide sufficient contrast between data types or objects that need to be easily distinguished. The mapping function can be any particular color (R, G, B) weighting that is acceptable, such as 33.3% R, 33.3%G, 33.3%B. It can also be a direct assignment that is totally arbitrary. The Windows environment is a good example of an application where even with color, it is not trivial to select a palette set that provides good distinction between all the data types, object types, and status types (selectable vs. non-selectable text in a menu). It is even more difficult to select a gray scale set that performs the same function.

In video mapping, the weighting function that is normally used is the one that has been used in television standards (NTSC) for years and generally follows the human eye response curve: gray shade = 30% R + 59% G + 11% B.

CONCLUSIONS

In the world of personal computer displays for portable applications, the LCD is dominant. While both monochrome and color displays are still supported, color now has the vast majority in terms of number of units produced. As time goes on and the TFT technology cost curve comes down, the active displays will become the majority. As multimedia capability becomes standard for all (at least most), portable PCs, TFT performance will be essential for live video. While it will be possible to generate a full color palette (probably specified at 16 M colors) by using 8-bit per primary TFT displays, that may not be the most cost-effective solution for all applications. Use of 4- to 6-bit per primary displays combined with the proper choice of controller palette extension techniques may be the most cost-effective choice for the majority of applications.

NOTES

NOTES

LIFE SUPPORT POLICY
SHARP components should not be used in medical devices with life support functions or in safety equipment (or similiar applications where component failure would result in loss of life or physical harm) without the written approval of an officer of the Sharp Corporation.

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